GEOLOGICAL SURVEY OF CANADA
BULLETIN 565

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B. Beauchamp, J.C. Harrison, J. Utting,
T.A. Brent, and S. Pinard

2001

Natural Resources Canada Ressources naturelles Canada

Canada

101-06053/

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Catalogue No. M42-565E
ISBN 0-660-18285-8

Available in Canada from
Geological Survey of Canada offices:

601 Booth Street
Ottawa, Ontario K1A 0E8

3303-33rd Street N.W.
Calgary, Alberta T2L 2A7

101-605 Robson Street
Vancouver, B.C. V6B 5J3

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Price subject to change without notice

Cover illustration

Typical landscape of southeastern Prince Patrick Island. Hummocks to the left of the helicopter are frost-shattered concretions weathering out of Middle Jurassic shales. Upper Paleozoic rocks described in this report are entirely covered by Mesozoic strata (GSCC photo 4705-1).

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Manuscript submitted: 2000-01
Approved for publication: 2000-11

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CARBONIFEROUS AND PERMIAN SUBSURFACE STRATIGRAPHY, PRINCE PATRICK ISLAND, NORTHWEST TERRITORIES, CANADIAN ARCTIC

Abstract

The Carboniferous and Permian succession of the Sverdrup Basin is extensive in the subsurface of northern Prince Patrick Island of the Canadian Arctic Archipelago, Northwest Territories. The succession is known from a series of seismic profiles and four exploratory wells drilled during the early 1970s. Upper Paleozoic strata are characterized by two broad packages. The lower package comprises Carboniferous to Lower Permian clastic and carbonate rocks truncated by a number of northwest–southeast-trending synsedimentary normal faults. The upper package is composed of Middle Permian (Guadalupian) clastic rocks that were deposited during a regime of passive subsidence following the cessation of faulting. These strata are separated from the underlying Lower Permian and Carboniferous succession by a widespread and locally angular unconformity.

Eleven upper Paleozoic formations have been identified on Prince Patrick Island: Borup Fiord, Canyon Fiord, Belcher Channel, Nansen, Raanes, Hare Fiord, 'unnamed clastics', Trappers Cove, Sabine Bay, van Hauen, and Trold Fiord.

The succession contains eight major unconformities that can be correlated over a significant area. Five of these unconformities were encountered in three of the drilled wells. Three additional unconformities were observed on seismic profiles only. The eight unconformities and the seven transgressive–regressive sequences between them have been traced seismically using a series of profiles. The ages of these sequences are Serpukhovian(?), Bashkirian–Kasimovian, Gzhelian–Sakmarian, Sakmarian–Artinskian, Kungurian, Roadian–Wordian and Capitanian(?).

The Carboniferous and Permian geological history of Prince Patrick Island includes a complex succession of events whereby tectonic pulses, as evidenced by brittle deformation, alternated with episodes of tectonic quiescence and passive subsidence. Climatic conditions evolved from warm and relatively arid during the Bashkirian–Sakmarian interval to increasingly cooler during the Artinskian–Capitanian(?). More humid conditions were also established during the Kungurian. A major river system fed the Prince Patrick area with large amounts of clastic material during the Artinksian–Guadalupian interval. The current geological setting of the area suggests the presence of many unexplored oil and gas plays. Unfortunately, the succession lies too deeply in the subsurface to envision any mineral exploration effort in the future.

Résumé

La succession carbonifère et permienne du bassin de Sverdrup occupe une surperficie importante dans la subsurface de l'île de Prince Patrick de l'archipel Arctique, dans les Territoires du Nord-Ouest. Nos connaissances sur la succession du Paléozoique supérieur proviennent d'une série de profils séismiques et de quatre puits d'exploration qui ont été forés au début des années soixante-dix. La succession du Paléozoïque supérieur est caractérisée par deux vastes assemblages. L'assemblage inférieur comprend des roches clastiques et des roches carbonatées du Carbonifère et du Permien inférieur qui sont recoupées par un certain nombre de failles synsédimentaires à jeu normal d'orientation nord-ouest-sud-est. L'assemblage supérieur est composé de roches clastiques du Permien moyen (Guadalupien) qui se sont déposées lors d'un régime de subsidence passive après que les failles eurent cessé de jouer. Ces strates sont séparées de la succession sous-jacente du Carbonifère et du Permien inférieur par une discordance de grande étendue, localement angulaire.

Onze formations du Paléozoique supérieur ont été identifiées dans l'île de Prince Patrick, soit les formations de Borup Fiord, de Canyon Fiord, de Belcher Channel, de Nansen, de Raanes, de Hare Fiord, de «roches clastiques non dénommées», de Trappers Cove, de Sabine Bay, de van Hauen et de Trold Fiord.

La succession renferme huit discordances importantes qui peuvent être corrélées sur de grandes distances. Cinq de ces discordances ont été recoupées dans trois des puits forés. Trois autres discordances ont été observées uniquement sur les profils sismiques. Les huit discordances et les sept séquences de trangression-régression qu'elles encadrent ont pu être distinguées et tracées à l'aide d'une série de profils sismiques. Ces séquences sont d'âge serpukhovien(?), bashkirien–kasimovien, gzhelien–sakmarien, sakmarien–artinskien, kungurien, roadien–wordien, et capitanien(?).

L'histoire géologique de l'île de Prince Patrick au Carbonifère et au Permien est marquée par une suite complexe d'évènements où des périodes d'activité tectonique, mises en évidence par des structures de déformation cassante, ont alterné avec des épisodes de calme tectonique et de subsidence passive. Les conditions climatiques ont évolué de chaudes et relativement arides durant l'intervalle du Baskirien–Sakmarien à des conditions progressivement plus froides durant l'intervalle de l'Artinskien–Capitanien(?). Des conditions plus humides ont existé également lors du Kungurien. Un système fluvial majeur a déversé des quantités importantes de sédiments clastiques dans la région de l'île Prince Patrick au cours de l'intervalle de l'Artinskien–Guadalupien. Le cadre géologique actuel de la région permet de supposer qu'il y gaz. Cependant, la succession est enfouie trop profondément pour envisager toute forme d'exploration minérale dans l'avenir.

Summary

The Carboniferous and Permian succession of the Sverdrup Basin is extensive in the subsurface of northern Prince Patrick Island Island of the Canadian Arctic Archipelago, Northwest Territories. The upper Paleozoic succession is known from a series of seismic profiles and four exploratory wells (Intrepid Inlet H-49, Jameson Bay C-31, Andreasen L-32, and Satellite F-68) that were drilled during the early 1970s. This bulletin synthesizes a multidisciplinary study that combined the lithological and petrographic analyses of well log, cuttings and cores, the paleontological age assessment of palynomorphs, small foraminifers, and fusulinaceans, and the examination and interpretation of seismic profiles.

A widespread angular unconformity lies between Carboniferous and younger strata of the Sverdrup Basin and Devonian and older strata of the Franklinian basement, the result of the uplift and erosion of Franklinian strata during the middle Devonian to earliest Carboniferous (Ellesmerian Orogeny). Carboniferous and younger strata were mildy deformed and uplifted during the Tertiary Eurekan Orogeny. The Carboniferous and Permian succession of Prince Patrick Island is characterized by two broad packages. The lower package comprises Carboniferous to Lower Permian clastic and carbonate rocks truncated by a number of northwest–southeast-trending synsedimentary normal faults. The upper package is composed of Middle Permian (Guadalupian) clastic rocks that were deposited during a regime of passive subsidence following the cessation of faulting. These strata are separated from the underlying Lower Permian and Carboniferous succession by a widespread and locally angular unconformity.

Eleven upper Paleozoic formations have been identified on Prince Patrick Island: Borup Fiord (Serpukhovian(?) red sandstone, conglomerate), Canyon Fiord (Bashkirian–Sakmarian sandstone, shale, limestone), Belcher Channel (Sakmarian limestone, sandstone, shale), Nansen (Bashkirian–Sakmarian limestone), Raanes (Sakmarian mixed clastic–carbonate), Hare Fiord (Bashkirian–Sakmarian shale, siltstone, limestone), 'unnamed clastics' (Artinskian sandstone, siltstone, shale), Trappers Cove (Artinskian–Kungurian shale, siltstone), Sabine Bay (Kungurian red shale, sandstone), van Hauen (Kungurian–Wordian dark shale, siltstone, limestone), and Trold Fiord (Wordian–Capitanian(?) sandstone, siltstone).

The upper Paleozoic succession of Prince Patrick Island contains eight major unconformities that can be correlated over a significant area. Five of these unconformities were encountered in Jameson Bay C-31, Intrepid Inlet H-49, and Andreasen L-32. Three additional unconformities were observed on seismic profiles only. The eight unconformities and the seven transgressive–regressive sequences between them have been traced seismically using a series of profiles. The ages of these sequences are Serpukhovian(?), Bashkirian–Kasimovian, Gzhelian–Sakmarian, Sakmarian–Artinskian, Kungurian, Roadian–Wordian, and Capitanian(?).

The Carboniferous and Permian geological history of Prince Patrick Island includes a complex succession of events whereby tectonic pulses, as evidenced by brittle deformation, alternated with episodes of apparent tectonic quiescence and passive subsidence. The principal direction of Serpukhovian(?) and Bashkirian extension on Prince Patrick Island was the same as throughout the Sverdrup Basin – anywhere from north–south to northwest–southeast. In addition, it is believed that three pulses of southeast-directed compressional tectonics affected Prince Patrick Island during the Gzhelian–Asselian, Sakmarian, and Kungurian intervals. There appears to be a temporal, and

likely genetic link, between the various Upper Carboniferous and Lower Permian tectonic pulses and the major stratigraphic sequences.

The various geological events that affected the area can be summarized as follows: 1) an episode of Serpukhovian(?) rifting; 2) a second pulse of rifting during the Bashkirian; 3) a long episode of apparent tectonic quiescence and passive subsidence during the Moscovian–Kasimovian time interval that allowed shelf carbonate to prograde basinward; 4) an episode of tectonic activity (compression) during the Gzhelian and early part of the Asselian, which segregated the area into a series of northwest–southeast tectonic depressions; 5) a regime of passive subsidence later in the Asselian and early in the Sakmarian that allowed shelf carbonate to prograde basinward; 6) a renewed episode of tectonic activity (compression) during the later part of the Sakmarian that resulted in differential subsidence along various fault segments; 7) an Artinskian regime of passive subsidence that allowed a broad clastic ramp fed by a large, extrabasinal river system to develop; 8) the Kungurian development of a large, nonmarine subbasin in the southern areas; 9) Kungurian tectonic activity (Melvillian Disturbance) which resulted in the accumulation of sandstone and pebble conglomerate derived from both local and extra-basinal sources; 10) a Roadian, rapid rise in relative sea level that drowned the shallow shelf areas and flooded the craton; 11) Wordian passive subsidence that led to the progradation of a significant clastic apron over northern Prince Patrick Island; 12) a Capitanian(?) rise in relative sea level that resulted in the progressive backstepping of the clastic depositional system; and 13) widespread subaerial exposure and erosion at the end of the Guadalupian.

Climatic conditions evolved from warm and relatively arid during the Bashkirian–Sakmarian interval to increasingly cooler during the Artinskian–Capitanian(?) interval. More humid conditions were also established during the Kungurian. A major river system fed the Prince Patrick area with large amounts of clastic material, starting during the Artinskian and climaxing during the Guadalupian. It is believed that the bulk of the Permian clastic apron on Prince Patrick Island contains material eroded from the Devonian clastic wedge to the south.

The current geological setting of the area suggests the presence of many unexplored oil and gas plays. A large segment of the Upper Carboniferous and Permian succession lies within the oil window of thermal maturation and/or within the wet gas and condensates zone. Potential source rocks, as well as variably porous clastic horizons, likely occur at various levels in the succession. But the succession lies too deeply in the subsurface to envision any mineral exploration effort in the future even though the area displays many settings potentially ideal for a variety of base metal deposits.

Sommaire

La succession carbonifère et permienne du bassin de Sverdrup occupe une surperficie importante dans la subsurface de l'île de Prince Patrick de l'archipel Arctique, dans les Territoires du Nord-Ouest. Nos connaissances sur la succession du Paléozoique supérieur proviennent d'une série de profils sismiques et de quatre puits d'exploration (Intrepid Inlet H-49, Jameson Bay C-31, Andreasen L-32 et Satellite F-68) qui ont été forés au début des années soixante-dix. Le présent bulletin fait la synthèse d'une étude multidisciplinaire qui combine l'analyse lithologique et pétrographique de diagraphies, de débris et de carottes de forage, l'évaluation paléontologique de l'âge de palynomorphes, de petits foraminifères et de fusulinidés, ainsi que l'examen et l'interprétation de profils sismiques.

Une discordance angulaire de grande étendue sépare les strates carbonifères et plus récentes du bassin de Sverdrup des strates dévoniennes et plus anciennes du socle franklinien. Cette discordance résulte du soulèvement et de l'érosion des strates frankliennes durant l'intervalle du Dévonien moyen au Carbonifère initial (orogenèse ellesmérienne). Les strates carbonifères et plus récentes ont été légèrement déformées et soulevées durant l'orogenèse eurékienne du Tertiaire.

La succession du Carbonifère et du Permien de l'île Prince Patrick est caractérisée par deux vastes assemblages. L'assemblage inférieur comprend des roches clastiques et des roches carbonatées du Carbonifère et du Permien inférieur qui sont recoupées par un certain nombre de failles synsédimentaires à jeu normal d'orientation nord-ouest-sud-est. L'assemblage supérieur est composé de roches clastiques du Permien moyen (Guadalupien) qui se sont déposées lors d'un régime de subsidence passive après que les failles eurent cessé de jouer. Ces strates sont séparées de la succession sous-jacente du Carbonifère et du Permien inférieur par une discordance, de grande étendue, localement angulaire.

Onze formations du Paléozoique supérieur ont été identifiées dans l'île Prince Patrick, soit les formations de Borup Fiord (grès rouges et conglomérats serpukhoviens(?)), de Canyon Fiord (grès, shales, et calcaires bashkiriens à sakmariens), de Belcher Channel (calcaires, grès, et shales sakmariens), de Nansen (calcaires bashkiriens à sakmariens), de Raanes (roches mixtes clastiques et carbonatées sakmariennes), de Hare Fiord (shales, siltstones, et calcaires bashkiriens à sakmariens), de «roches clastique non dénommées» (grès, siltstones, et shales artinksiens), de Trappers Cove (shales et siltstones artinskiens), de Sabine Bay (shales rouges et grès kunguriens), de van Hauen (shales et siltstones foncés roadiens et wordiens) et de Trold Fiord (grès et siltstones wordiens et capitaniens(?)).

La succession du Paléozoique supérieur de l'ile de Prince Patrick renferme huit discordances importantes qui peuvent être corrélés sur de grandes distances. Cinq de ces discordances ont été recoupées dans les puits Jameson Bay C-31, Intrepid Inlet H-49 et Andreasen L-32. Trois autres discordances ont été observées uniquement sur les profils sismiques. Ces huit discordances et les sept séquences de transgression–régression qu'elles encadrent ont pu être distinguées et tracées à l'aide d'une série de profils sismiques. Ces séquences sont d'âge serpukhovien(?), bashkirien–kasimovien, gzhelien–sakmarien, sakmarien–artinskien, kungurien, roadien–wordien, et capitanien(?).

L'histoire géologique de l'île Prince Patrick au Carbonifère et au Permien est marquée par une suite complexe d'évènements où des périodes d'activité tectonique, mises en évidence par des structures de déformation cassante, ont alterné avec des épisodes de calme tectonique et de subsidence passive. La direction principale de l'étirement au Serpukhovien(?) et au Bashkirien dans l'île Prince Patrick était la même que partout ailleurs dans le bassin de Sverdrup, soit quelque part entre nord–sud et nord ouest–sud-est. En outre, trois épisodes de compression à vergence sud-est auraient touché l'île Prince Patrick durant les intervalles du Gzhelien–Assélien, du Sakmarien et du Kungurien. Par ailleurs, il semble exister un lien chronologique, et probablement génétique, entre les divers épisodes tectoniques et les principales séquences stratigraphiques du Carbonifère supérieur et du Permien inférieur.

Les divers évènements géologiques auxquels la région a été soumise peuvent se résumér comme suit: 1) un épisode de rifting au Serpukhovien(?); 2) un second épisode de rifting lors du Bashkirien; 3) un long intervalle de calme tectonique apparent et de subsidence passive durant l'intervalle du Moscovien–Kasimovien qui entraîne la progradation de sédiments carbonatés de plate-forme vers le bassin; 4) un épisode d'activité tectonique (compression) durant le Gzhelian et au début de l'Assélien qui mène à la ségmentation de la région en plusieurs dépressions tectoniques d'orientation nord-ouest–sud-est; 5) un régime de subsidence passive plus tard durant l'Assélien et au début du Sakmarian permettant la progradation de sédiments carbonatés de plate-forme vers le basin; 6) un nouvel épisode d'activité tectonique (compression) vers la fin du Sakmarien provoquant une subsidence différentielle le long des diverses failles; 7) un régime de subsidence passive durant l'Artinskien conduisant à la formation d'une vaste rampe de sédiments clastiques, alimentée par un important système fluvial extrabassinal; 8) la formation au Kungurien d'un vaste sous-bassin non-marin dans les régions méridionales; 9) une activité tectonique au Kungurienne (accident melvillien) causant l'accumulation de grès et de conglomérats à cailloux dérivés à la fois de sources locales et de sources extrabassinales; 10) une montée rapide du niveau de la mer relatif au Roadien ennoyant les plates-formes peu profondes et inondant le craton; 11) une subsidence passive au Wordien menant à la progradation d'un prisme de roches clastiques important partout au nord de l'île Prince Patrick; 12) une montée rapide du niveau de la mer relatif au Capitanien(?) causant la rétrogradation du système de dépôt clastique; et 13) une émergence et une érosion à grande échelle à la fin du Guadalupien.

Les conditions climatiques ont évolué de chaudes et relativement aride durant l'intervalle du Baskirien–Sakmarien à des conditions progressivement plus froides durant l'intervalle l'Artinskien–Capitanien(?). Des conditions plus humides ont également existé lors du Kungurien. Un système fluvial majeur a déversé des quantités importantes de sédiments clastiques dans la région de l'île Prince Patrick au cours de l'intervalle de l'Artinskien–Guadalupien. Le gros du prisme de roches clastiques du Permien dans l'île Prince Patrick se compose de matériaux provenant de l'érosion du prisme de roches clastiques du Dévonien situé plus au sud.

La cadre géologique actuel de la région laisse supposer qu'il y existe plusieurs zones intéressantes, mais inexplorées, quant à la présence de pétrole ou de gaz. Une grande portion de la succession du Carbonifère et du Permien se situe à l'intérieur de la fenêtre de génération du pétrole ou dans la zone des gaz humides et des condensats. Des roches mères potentielles existent à divers niveaux dans la succession, de même que des horizons de roches clastiques plus ou moins poreux. Cependant, la succession est enfouie trop profondément pour envisager toute forme d'exploration minérale dans l'avenir, bien que la région présente plusieurs contextes favorables à la présence possible d'une variété de minéralisations de métaux usuels.

INTRODUCTION

The Carboniferous and Permian succession of the Sverdrup Basin (Fig. 1) is not exposed on Prince Patrick Island but occurs extensively in the subsurface in the northern part of the island, where it constitutes a northwest–southeast belt that intersects the head of Intrepid Inlet (Fig. 2). The upper Paleozoic succession is known from a series of seismic profiles and four exploratory wells that were drilled between 1971 and 1973. These four wells are Intrepid Inlet H-49, Jameson Bay C-31, Andreasen L-32, and Satellite F-68 (Fig. 2).

This bulletin is the first published account of the Carboniferous and Permian succession of Prince Patrick Island. Sverdrup Basin-wide paleogeographic maps displaying upper Paleozoic facies belts intersecting Prince Patrick Island have been published by various authors (Beauchamp, 1995; Embry, 1993; Davies and Nassichuk, 1991; Meneley et al., 1975; Thorsteinsson, 1974). Minor reference to the island's subsurface data can be found in Beauchamp and Henderson (1994) and Utting et al. (1989b).

The present study included the description and interpretation of well cuttings and cores by B. Beauchamp, the stratigraphic and structural interpretation of seismic profiles by B. Beauchamp, J.C. Harrison, and T.A. Brent, and the paleontological examination of material from cores and cuttings by J. Utting (palynology) and S. Pinard (small foraminifers). Paleontological data and interpretations are presented in Appendix 1, which also contains biostratigraphic information on three fusulinacean-bearing samples provided by L. Rui. Geochemical data pertaining to source rock potential are contained in Appendix 2.

In this bulletin, the thicknesses of stratigraphic units are expressed in metres (m), whereas direct references to log data are in feet (ft., with metric conversions), because this was the original unit of well data acquisition. Seismic two-way times are expressed in milliseconds (ms) and seismic velocities in feet per second (ft./s).

The ages of Permian formations and sequences are expressed according to the chronostratigraphic subdivisions recently accepted by the Subcommission on Permian

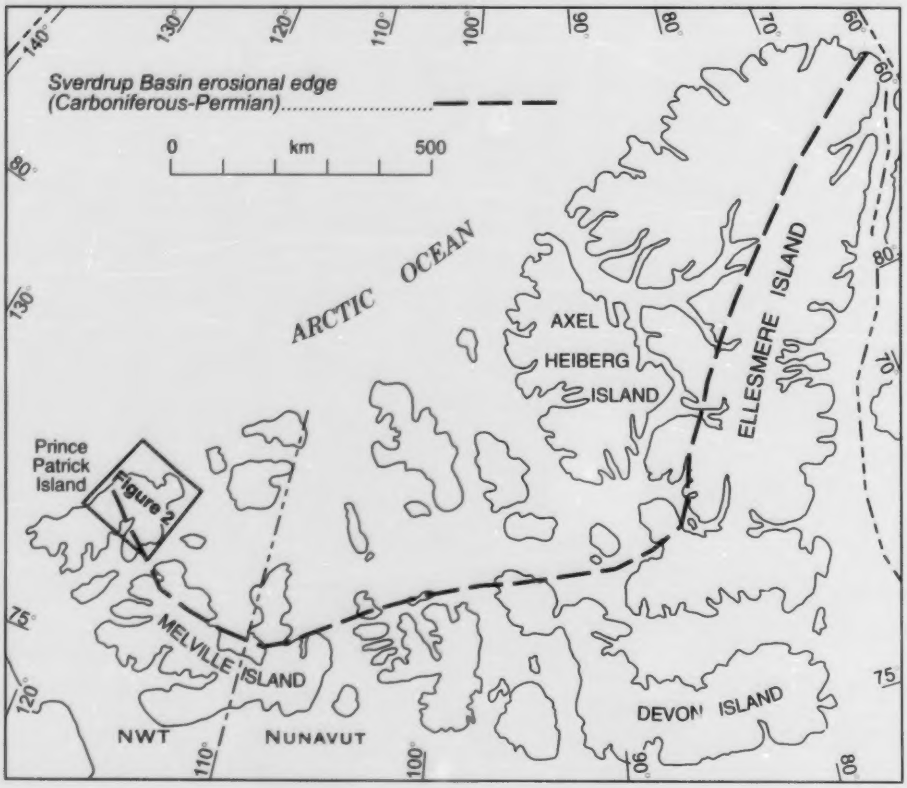

Figure 1. The Canadian Arctic Archipelago showing outline of Sverdrup Basin and area displayed in Figure 2.

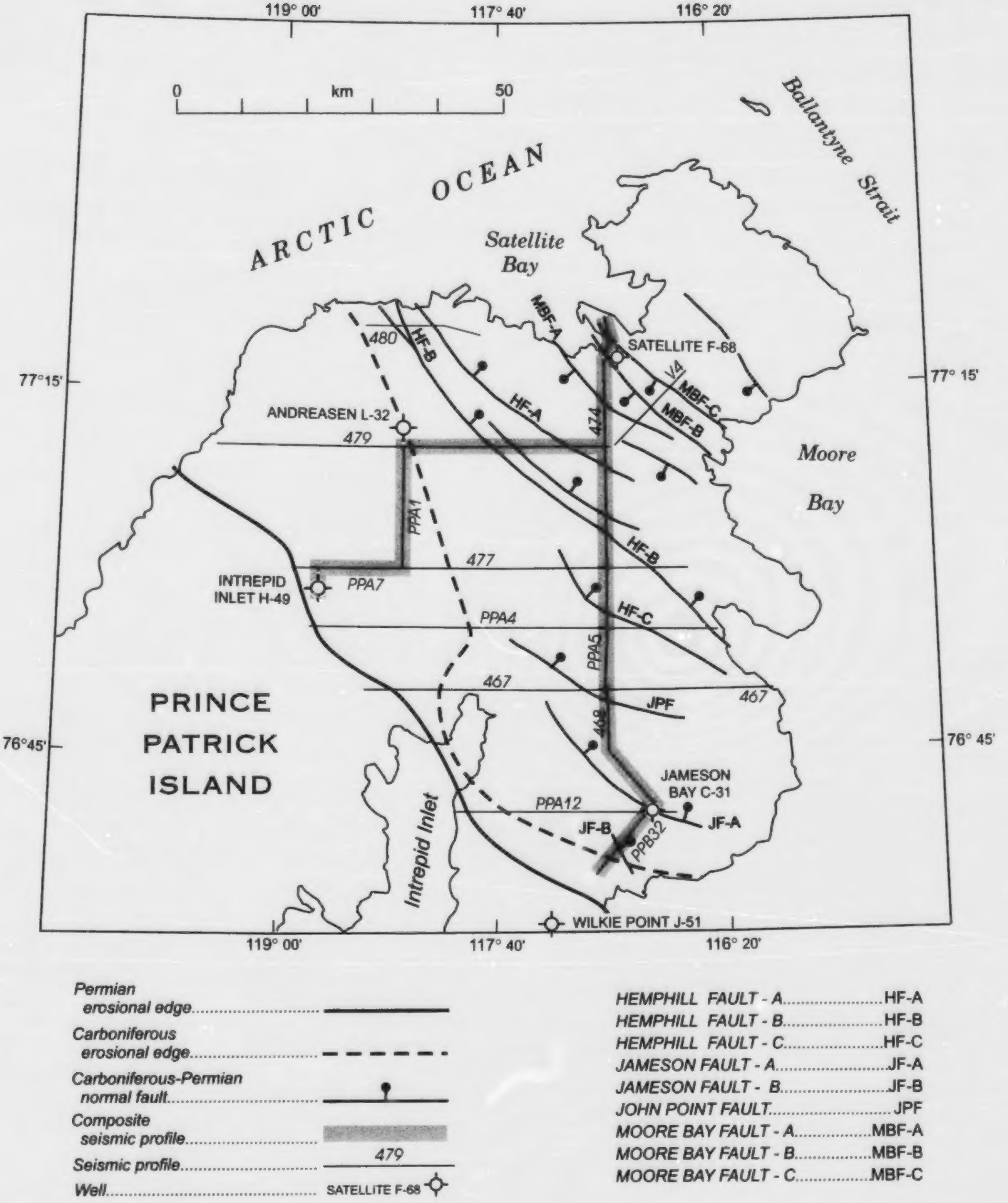

Figure 2. *Northern Prince Patrick Island showing Carboniferous and Permian erosional edges, named basement-parallel late Paleozoic faults, well locations, and seismic profiles.*

Stratigraphy (Jin et al., 1997). The Permian is divided into three series (Fig. 3): the Cisuralian (Early Permian) Series (Asselian, Sakmarian, Artinskian, and Kungurian stages), Guadalupian (Middle Permian) Series (Roadian, Wordian, and Capitanian stages), and Lopingian (Late Permian) Series (Wuchiapingian and Changhsingian stages). This chronostratigraphic scheme differs substantially from the two-fold system traditionally used in the Sverdrup Basin, whereby Roadian (or Ufimian) and older Permian formations were included in a Lower Permian subdivision, and Wordian (or Kazanian) and younger Permian formations were part of an Upper Permian subdivision (e.g., Utting, 1994; Beauchamp, 1995).

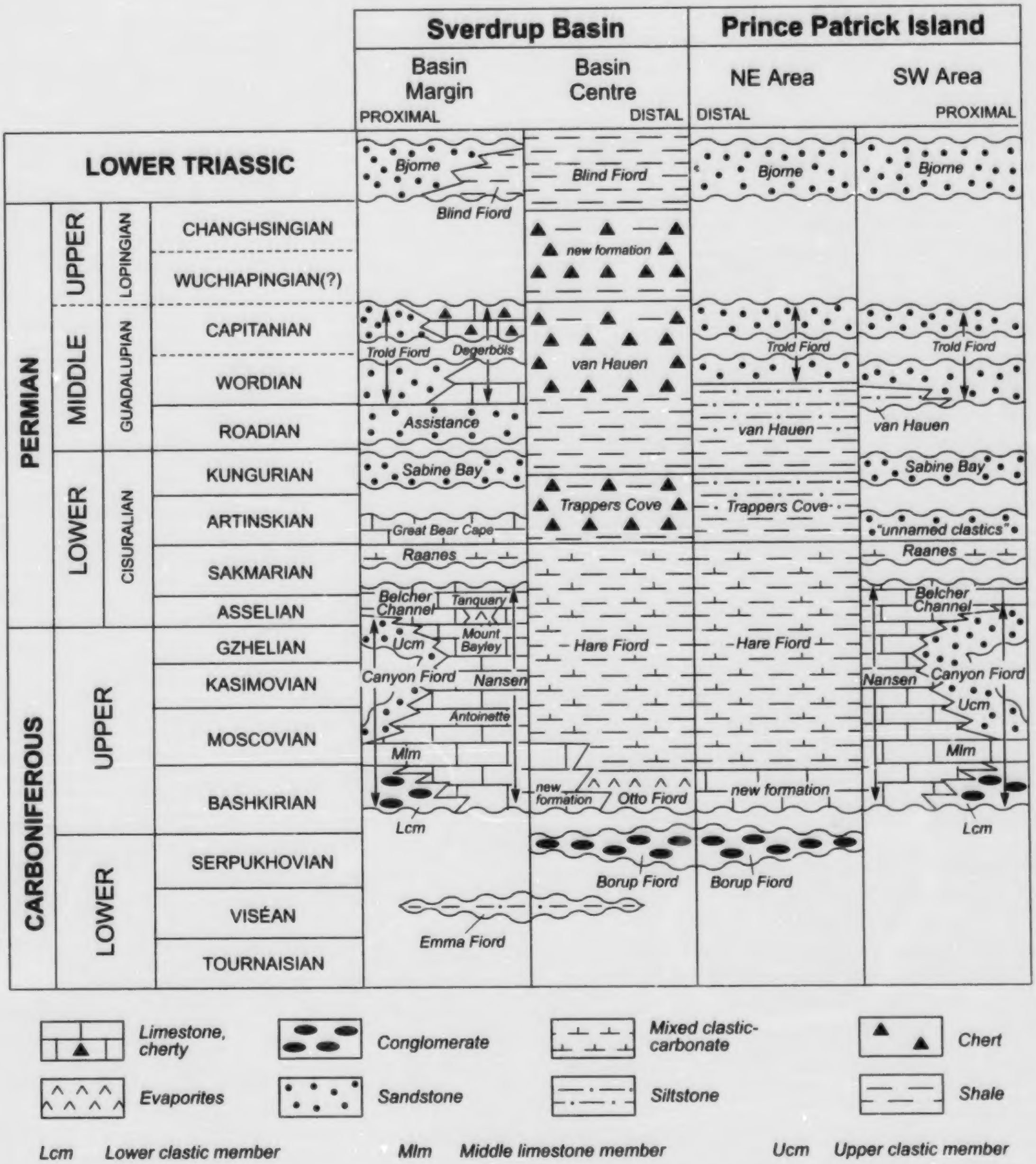

Figure 3. Schematic representation of Carboniferous, Permian, and Lower Triassic formations in the Sverdrup Basin and corresponding units in the subsurface of Prince Patrick Island. Modified from Beauchamp et al. (1998) and Beauchamp (1995).

ACKNOWLEDGMENTS

The authors are grateful to Lin Rui for paleontological assistance, Peter Neelands for cartographic advice, Jo Monro Gray for editing, Claudia Thompson for document composition and to Keith Dewing, Jim Dixon and Ashton Embry for their review of the manuscript and insightful comments.

REGIONAL SETTING

The Carboniferous and Permian succession of Prince Patrick Island is part of the Sverdrup Basin, a 1200 km long northeasterly trending depocentre that extends from Prince Patrick Island to Ellesmere Island (Fig. 1) in the Canadian Arctic Archipelago. A widespread angular unconformity lies between the Carboniferous and younger strata of the Sverdrup Basin and the Devonian and older strata of the Franklinian basement, a result of the uplift and erosion of Franklinian strata during the Middle Devonian to earliest Carboniferous (Ellesmerian Orogeny). Subsidence of the Sverdrup Basin was initiated through rifting in the Early Carboniferous. Fault-related subsidence prevailed during the Late Carboniferous and Early Permian. Most rift-related faults terminate below a widespread sub-Roadian (mid-Permian) unconformity, above which the younger Permian and most of the Mesozoic successions were deposited in response to passive subsidence. Strata of the Sverdrup Basin were uplifted during the Tertiary Eurekan Orogeny. Deformation was more intense in the eastern Arctic (Axel Heiberg, Ellesmere islands), where the succession is remarkably exposed. Only mild Tertiary deformation affected the western Arctic areas.

Upper Triassic sandstones (Norian Pat Bay Formation) are the oldest exposed strata of the Sverdrup Basin succession on Prince Patrick Island (Harrison, 1993). The upper Paleozoic succession lies entirely in the subsurface. In the southern areas, the Carboniferous and Permian erosional edges strike in a northwest–southeast direction and intersect the head of Intrepid Inlet (Fig. 2) at depths averaging 1200 m. In the northern areas near Ballantyne Strait, the top Permian level lies below a depth of 2000 m and as much as 4 km of upper Paleozoic rocks are present.

The Carboniferous and Permian succession of Prince Patrick Island is characterized by two broad packages, as observed on seismic profiles (Fig. 4, 5). The lower package comprises Carboniferous to Lower Permian clastic and carbonate rocks truncated by a number of northwest–southeast-trending, normal faults. These faults, nine of which are named in Figure 2, are synsedimentary, rift-related structures associated with block rotation, footwall uplift, and and differential hanging wall subsidence (Fig. 4, 5). They are parallel to a series of thrust faults in the underlying Franklinian Basement. Six of these faults are down-to-basin, listric normal faults: Jameson Fault-A and -B, John Point Fault, and Hemphill Fault-C, -B and -A (Fig. 2, 4). Three additional faults are down-to-craton, listric normal faults: Moore Bay Fault-A, -B and -C (Fig. 2, 5). Poorly imaged, unnamed faults of similar polarity occur north of Moore Bay Fault-C (Fig. 2). The kinematic link between Devonian Ellesmerian compressional stuctures and Carboniferous and Permian extensional structures will be examined in detail in a future publication (Harrison et al., work in progress).

The upper package is composed of Middle Permian (Guadalupian) clastic rocks that were deposited during a regime of passive subsidence following the cessation of faulting (Fig. 4, 5). These strata are separated from the underlying Lower Permian and Carboniferous succession by a widespread, and, locally, angular unconformity, herein referred to as the mid-Permian unconformity, attesting to a phase of compression and structural inversion during the late Early Permian known as the Melvillian Disturbance. The Middle Permian succession is unconformably overlain by the Triassic and younger succession. Upper Permian strata and a conformable transition with the Triassic may occur near Ballantyne Strait. Minor displacement of Carboniferous and Permian strata occurred in response to Jurassic to Cretaceous extension and to mild Tertiary uplift and compression (Harrison et al., work in progress). The Moore Bay Anticline, which was penetrated by Satellite F-68, is one such Tertiary structure (Fig. 5).

LITHOSTRATIGRAPHY

The upper Paleozoic stratigraphy of Prince Patrick Island is depicted schematically in Figure 3. The name, top, lithological content, and stratigraphic position of each of the upper Paleozoic formations penetrated by the four wells are shown in Figures 6 and 7. The wells are tied to two regional seismic profiles flattened to the base Triassic (Fig. 8, 9). Nine upper Paleozoic formations were penetrated by drilling on Prince Patrick Island: the Canyon Fiord, Belcher Channel, Raanes, Hare Fiord, 'unnamed clastics', Trappers Cove, Sabine Bay, van Hauen, and Trold Fiord. Two additional units, the Borup Fiord and Nansen formations, are believed to occur beyond the limit of drilling, based on seismic stratigraphic interpretations.

Borup Fiord Formation

Definition and type section

The Borup Fiord Formation was defined by Thorsteinsson (1974) as a unit of red sandstone and conglomerate that lies at the base of the upper Paleozoic succession on northern Ellesmere and northern Axel Heiberg islands (Nassichuk

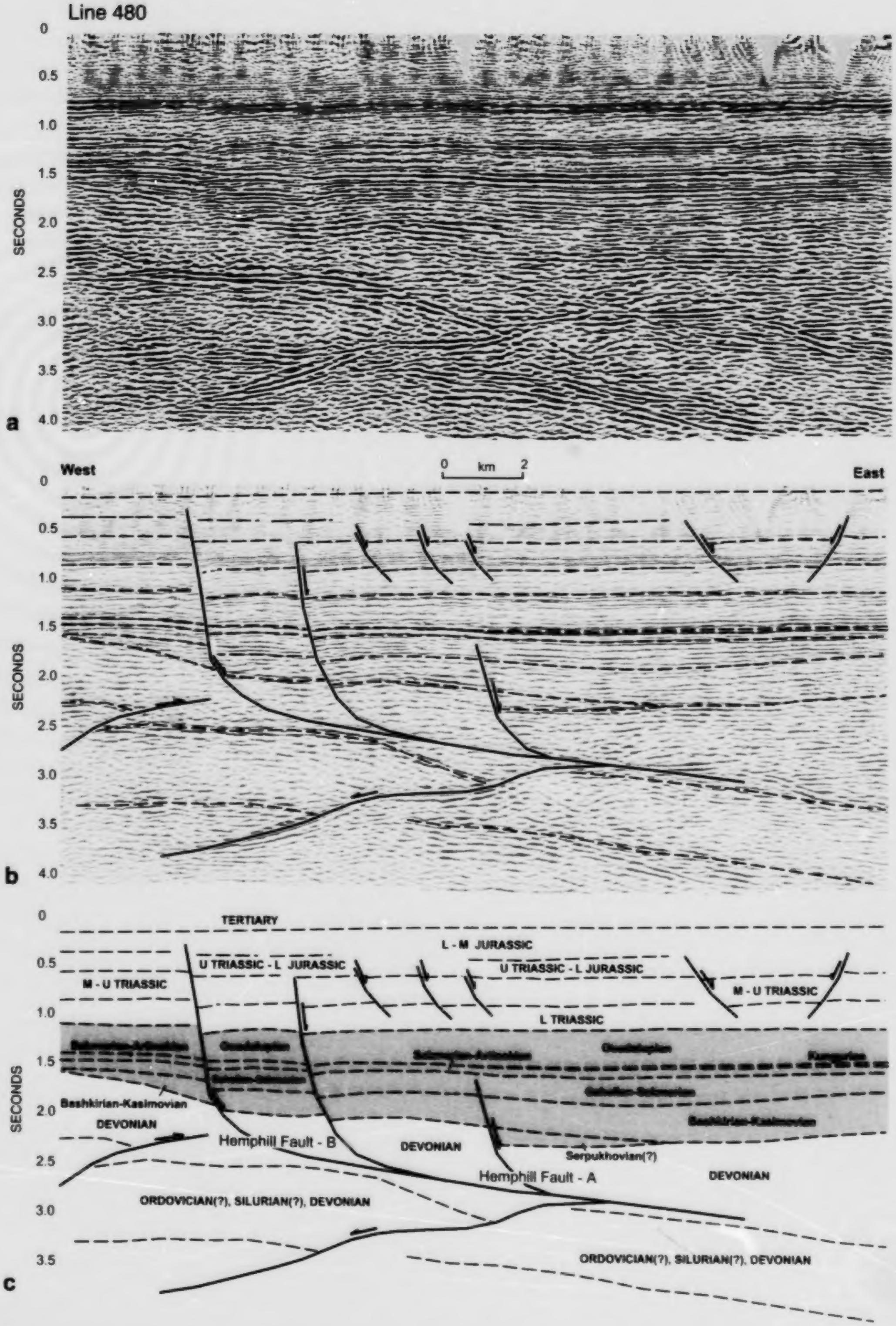

Figure 4. *Seismic profile 480.* ***a.*** *Uninterpreted.* ***b.*** *Stratigraphic and structural interpretation.* ***c.*** *Annotations. Shaded area in* ***c*** *is Carboniferous and Permian succession. See Figure 2 for location.*

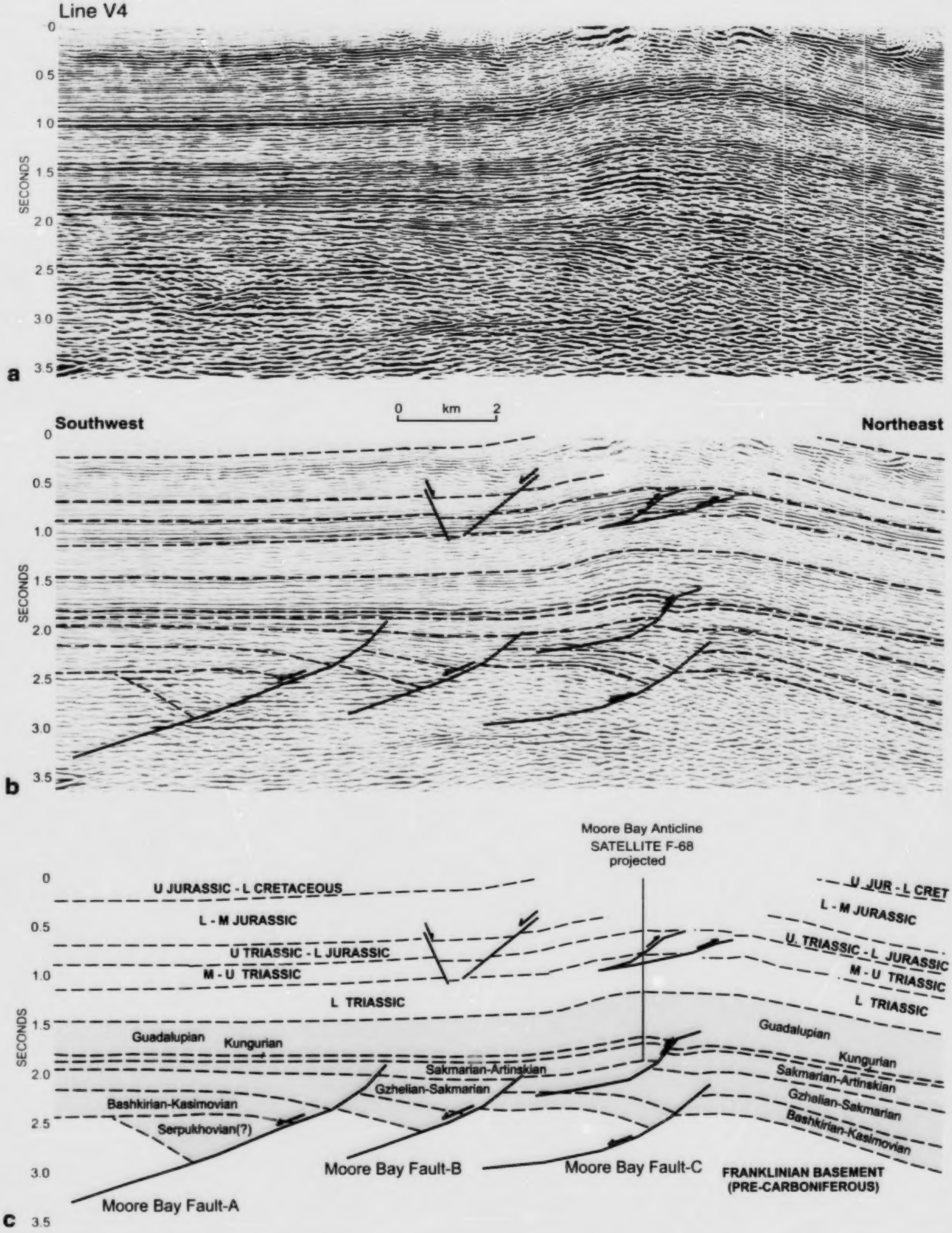

Figure 5. *Seismic profile V4.* ***a.*** *Uninterpreted.* ***b.*** *Stratigraphic and structural interpretation.* ***c.*** *Annotations. Shaded area in* ***c*** *is Carboniferous and Permian succession. See Figure 2 for location.*

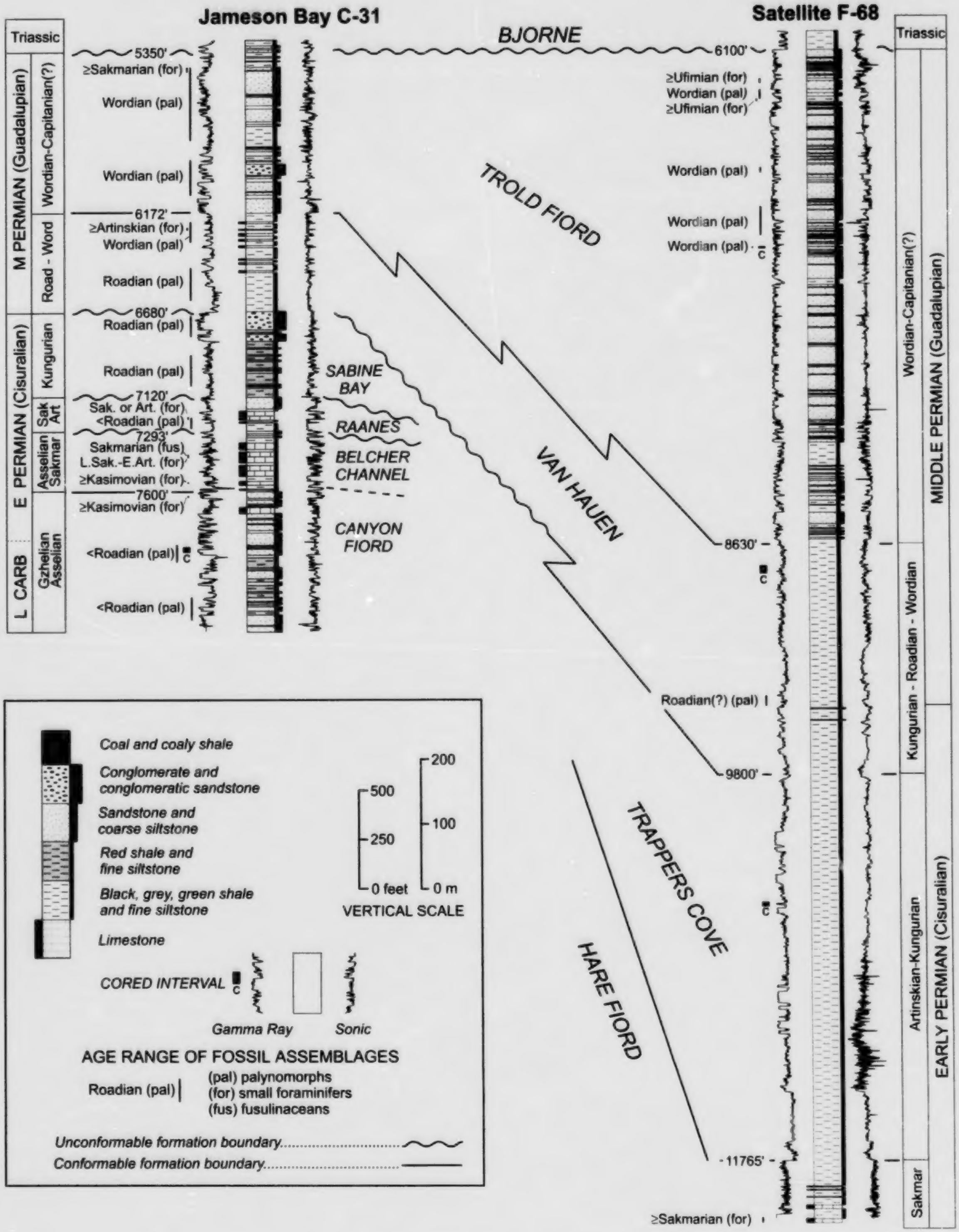

Figure 6. *Lithostratigraphic cross-section between Jameson Bay C-31 and Satellite F-68 showing gamma ray and sonic logs, lithologies, formation names and tops (in ft.), contact types, age ranges of fossil assemblages and correlations. Fossil data are listed in Appendix 1.*

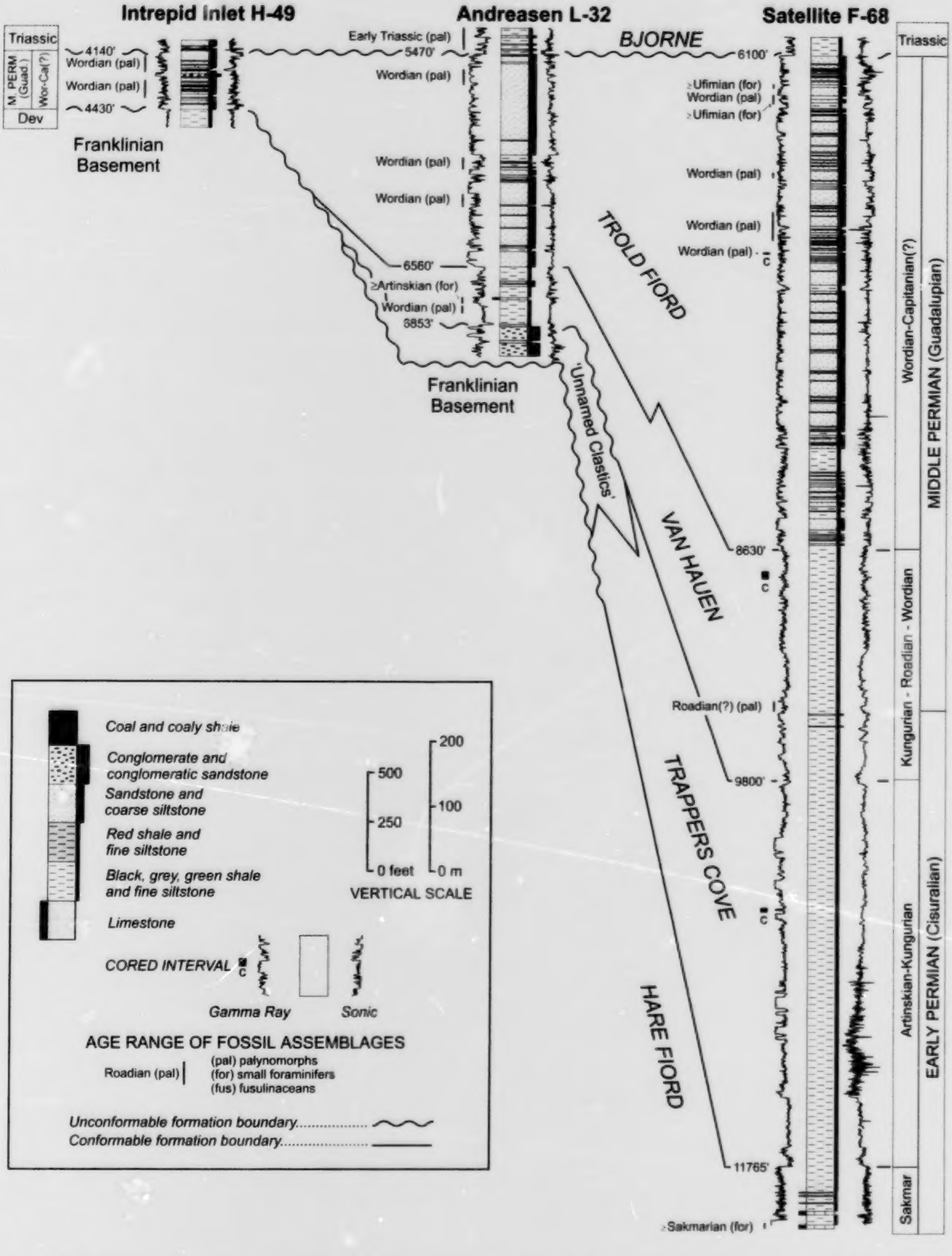

Figure 7. *Lithostratigraphic cross-section between Intrepid Inlet H-49, Andreasen L-32, and Satellite F-68 showing gamma ray and sonic logs, lithologies, formation names and tops (in ft.), contact types, age range of fossil assemblages, and correlations. Fossil data are listed in Appendix 1.*

and Davies, 1980; Trettin, 1988; Mayr, 1992; Thériault et al., 1993, 1995a, b). The Borup Fiord Formation lies directly upon the lower Paleozoic Franklinian basement, or is separated from the basement by the upper Viséan Emma Fiord Formation, a dark unit of shale, siltstone and minor limestone that outcrops sporadically along the northern and southern margins of the Sverdrup Basin (Fig. 3; Thorsteinsson, 1974; Davies and Nassichuk, 1988; Utting et al., 1989a). The Borup Fiord Formation is overlain either by evaporites of the Otto Fiord Formation or by carbonates of the Nansen or Hare Fiord Formation. The type section near Stepanov Creek, northern Ellesmere Island, is 120 m thick. Nearly 1 km of Borup Fiord strata have been documented from Yelverton Inlet, northern Ellesmere Island (Mayr, 1992).

Distribution, thickness, and sonic velocity

The Borup Fiord Formation is assigned to a wedge-shaped seismic unit that lies at the bottom of the upper Paleozoic succession in the hanging wall of Hemphill Fault-A and Moore Bay Fault-A, as observed on seismic lines 474 and 479 (Fig. 8, 9). The same unit was also observed on seismic lines 480 and V4 (Fig. 4, 5). This seismic interval ranges from zero to as much as 500 ms over short distances. Based on the known seismic velocity of younger drilled clastic-bearing formations one can speculate that the Borup Fiord Formation reaches a maximum thickness of 1 km or more in the subsurface of Prince Patrick Island.

Lithology

The Borup Fiord Formation on Prince Patrick Island is assumed to be compositionally similar to the known surface occurrences of the formation on Ellesmere and Axel Heiberg islands, where red sandstone and conglomerate, associated with minor mudstone, siltstone and limestone, constitute the dominant lithologies (Thériault et al., 1995a, b; Thorsteinsson, 1974). Variously developed calcrete crusts occur within the sandstone and conglomerate. Fossiliferous marine limestone occurs locally in the upper part of the formation.

Seismic expression

The seismic unit attributed to the Borup Fiord Formation comprises a series of faint reflectors superimposed upon strong horizontal multiples. The Borup Fiord reflectors dip 10 to 30° toward Hemphill Fault-A and Moore Fault-A, respectively, defining two wedge-shaped units that thicken toward, and abut against, these two faults (Fig. 8, 9).

Lower contact

The Borup Fiord Formation rests unconformably upon Devonian strata of the Franklinian basement.

Age and correlation

The age of the Borup Fiord Formation is generally assumed to be Serpukhovian (late Early Carboniferous), although foraminifers recovered from the upper part of the formation on Ellesmere Island may range into the Bashkirian (Thorsteinsson, 1974; Groves et al., 1994; Pinard and Mamet, 1998).

Depositional environment

Sedimentological studies of the Borup Fiord Formation on Ellesmere and Axel Heiberg islands have suggested that the bulk of the formation resulted from deposition within tectonically active half-grabens, during an early phase of rifting and crustal extension (Thériault et al., 1993, 1995a, b). According to Thériault et al. (1995a) alluvial fan and braidplain (mass-flow and stream-channel conglomerates) to sheetflood (sandstone and mudstone) depositional environments are represented by the formation. Variously developed pedogenic caliches occur throughout the formation.

Canyon Fiord Formation

Definition and type section

The name Canyon Fiord Formation was given by Troelsen (1950) to a 140 m thick unit of mostly carbonate rocks that outcrop near Caledonian Bay on the east coast of Canyon Fiord, southwest Ellesmere Island. Thorsteinsson (1974) expanded Troelsen's definition of the formation to include more than 1600 m of conglomerate, limestone and sandstone ranging in age from Bashkirian (early Late Carboniferous) to Sakmarian (Early Permian). The Canyon Fiord Formation is widely distributed along the surface and subsurface of the southern, eastern, and northern margins of the Sverdrup Basin, where its thickness varies from a feather-edge to as much as 2 km. The formation comprises three distinct units that have been assigned the informal names Lower clastic member, Middle limestone member, and Upper clastic member (Fig. 3; Beauchamp, 1987, 1995; Beauchamp et al., 1989b). These subdivisions have been recognized on Melville Island (Harrison, 1995; Riediger and Harrison, 1993), Grinnell Peninsula, Devon Island (Beauchamp and Thériault, 1994; Beauchamp et al., 1998), Raanes Peninsula,

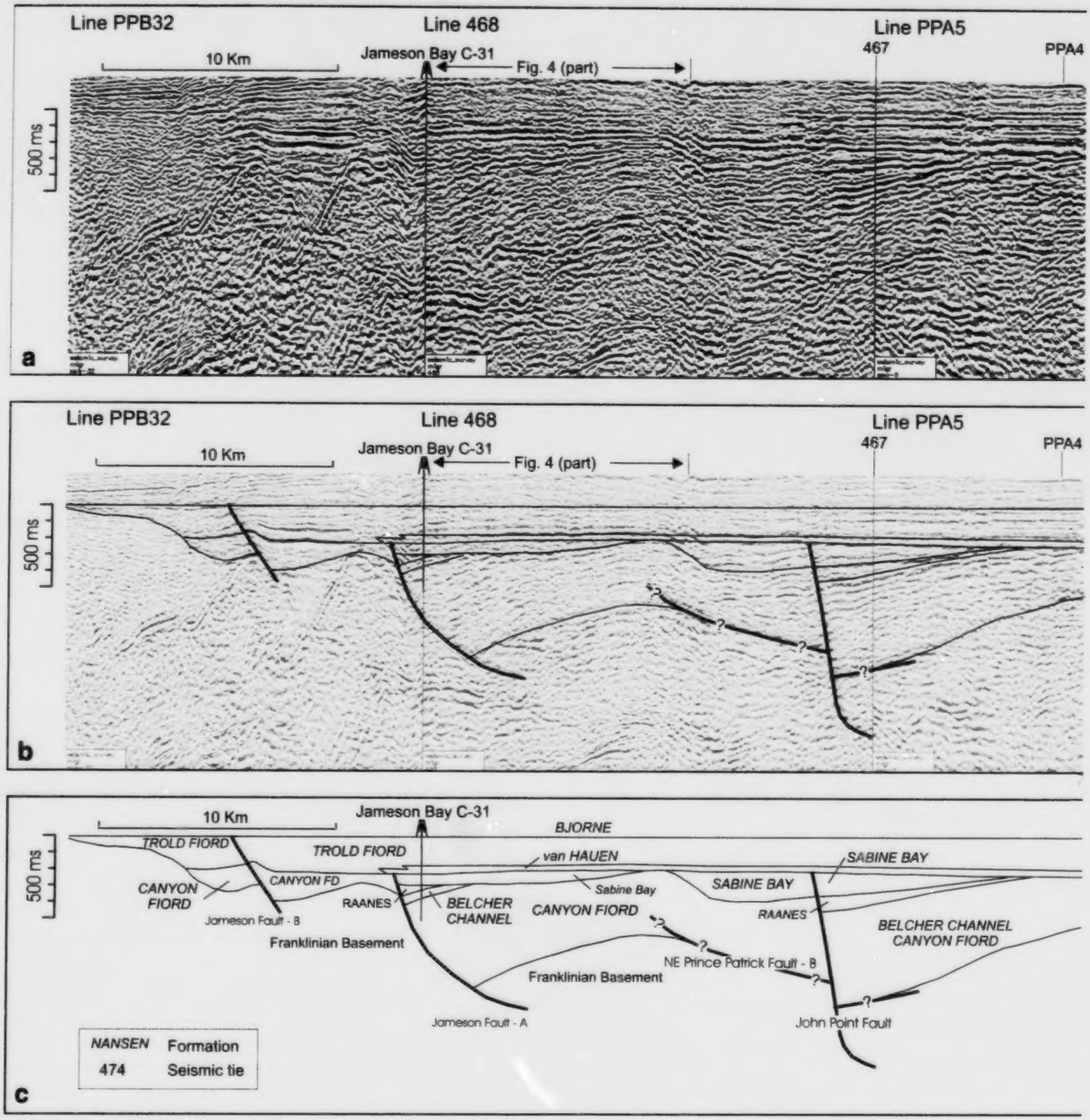

Figure 8. *Composite seismic profile C31-F68, flattened to base Triassic.* ***a.*** *Uninterpreted.* ***b.*** *Interpreted.* ***c.*** *Interpreted with lithostratigraphic units. See Figure 2 for location.*

southwest Ellesmere Island (Beauchamp, 1987; Thériault, 1991; Henderson et al., 1995), west-central Ellesmere Island (Thériault and Beauchamp, 1991), and northern Ellesmere Island (Mayr, 1992).

Distribution, thickness, and sonic velocity

The Canyon Fiord Formation occurs widely beneath northern Prince Patrick Island, but its thickness varies greatly over short distances, reflecting its irregular

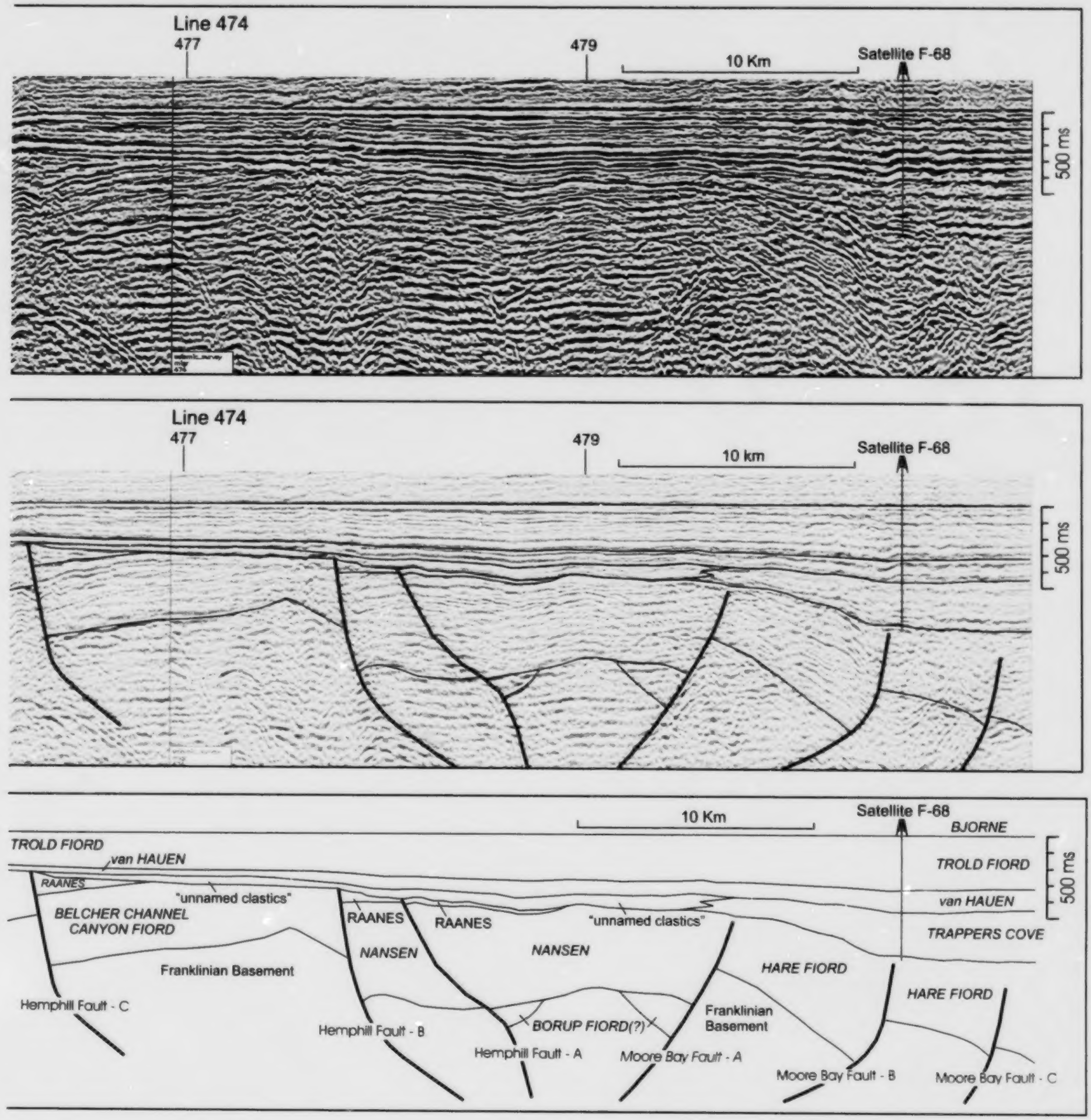

Figure 8. *Composite seismic profile C31-F68 continued.*

preservation in and out of fault-bounded depressions and uplifts. More than 220 m of the Canyon Fiord Formation (Upper clastic member) were encountered in the Jameson Bay C-31 well (7600 ft. to T.D.; 2316 m) (Fig. 6). The sonic velocity of that succession fluctuates between 12 000 and 16 000 ft./s.

Based on the seismic interpretations of Figure 8, the Canyon Fiord Formation is thickest within the tectonic depression associated with Jameson Fault-A, where it is about 600 ms-thick. This translates into a thickness of more than 1500 m. A similar thickness probably occurs along seismic line 467, where the undifferentiated Canyon Fiord–

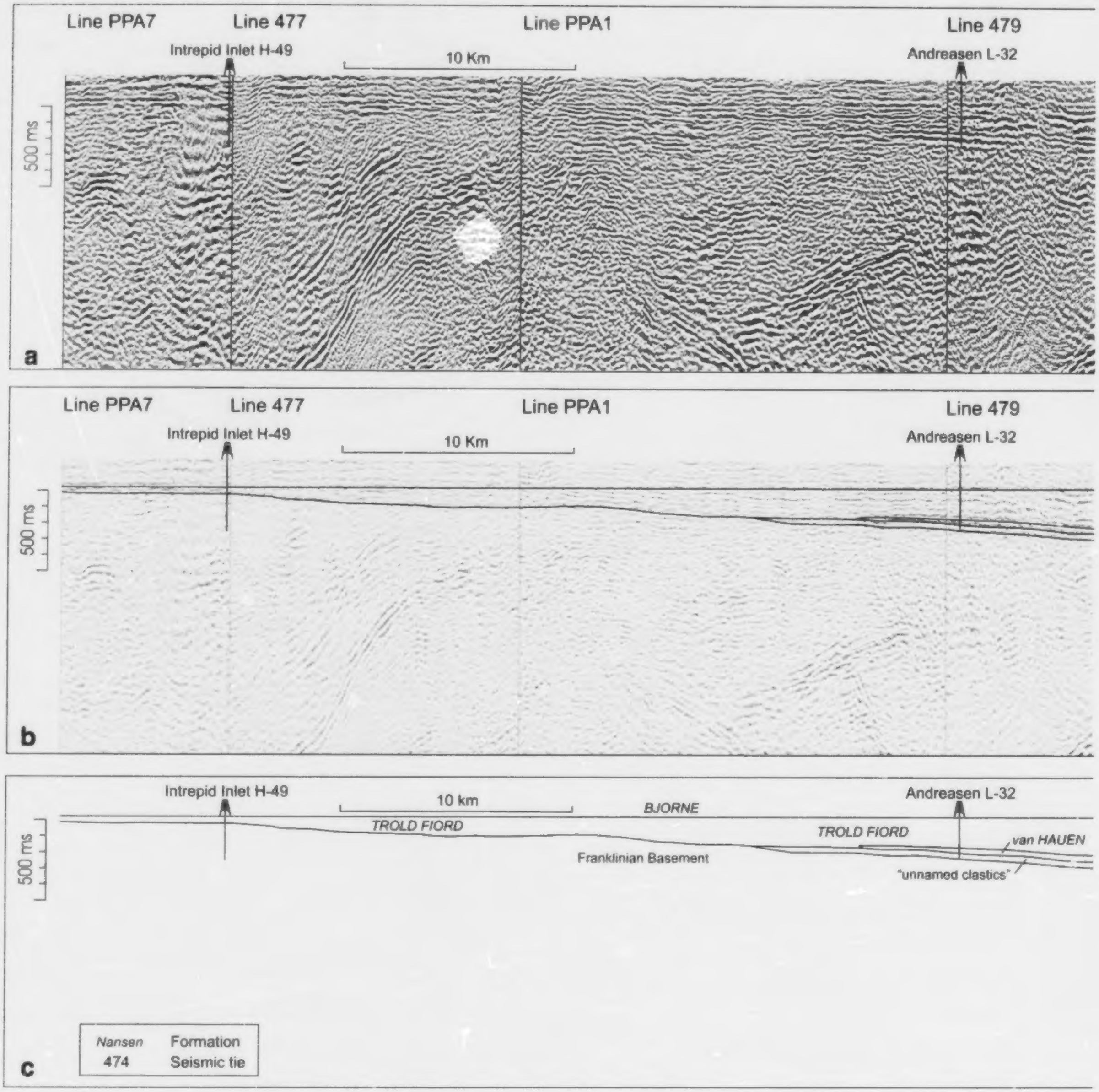

Figure 9. *Composite seismic profile H49-L32-F68, flattened to base Triassic.* ***a.*** *Uninterpreted.* ***b.*** *Interpreted.* ***c.*** *Interpreted with lithostratigraphic units. See Figure 2 for location.*

Belcher Channel couplet is up to 700 ms-thick, as discussed later under "Sequence stratigraphy".

Lithology

The Canyon Fiord succession penetrated by Jameson Bay C-31 comprises 220 m of pink, red and buff, fine to coarse-grained, variably calcareous sandstone interstratified with red shale and siltstone (Fig. 6). Calcareous grey shale and reddish-grey sandy limestone occurs locally. Terrigenous sand consists of generally well-sorted, angular to subangular, very fine- to medium-grained quartz (70–95%) and chert (5–30%). Most sandstone ranges from slightly to highly calcareous because of the presence of calcareous cements, generally an equigranular calcite phase, and the

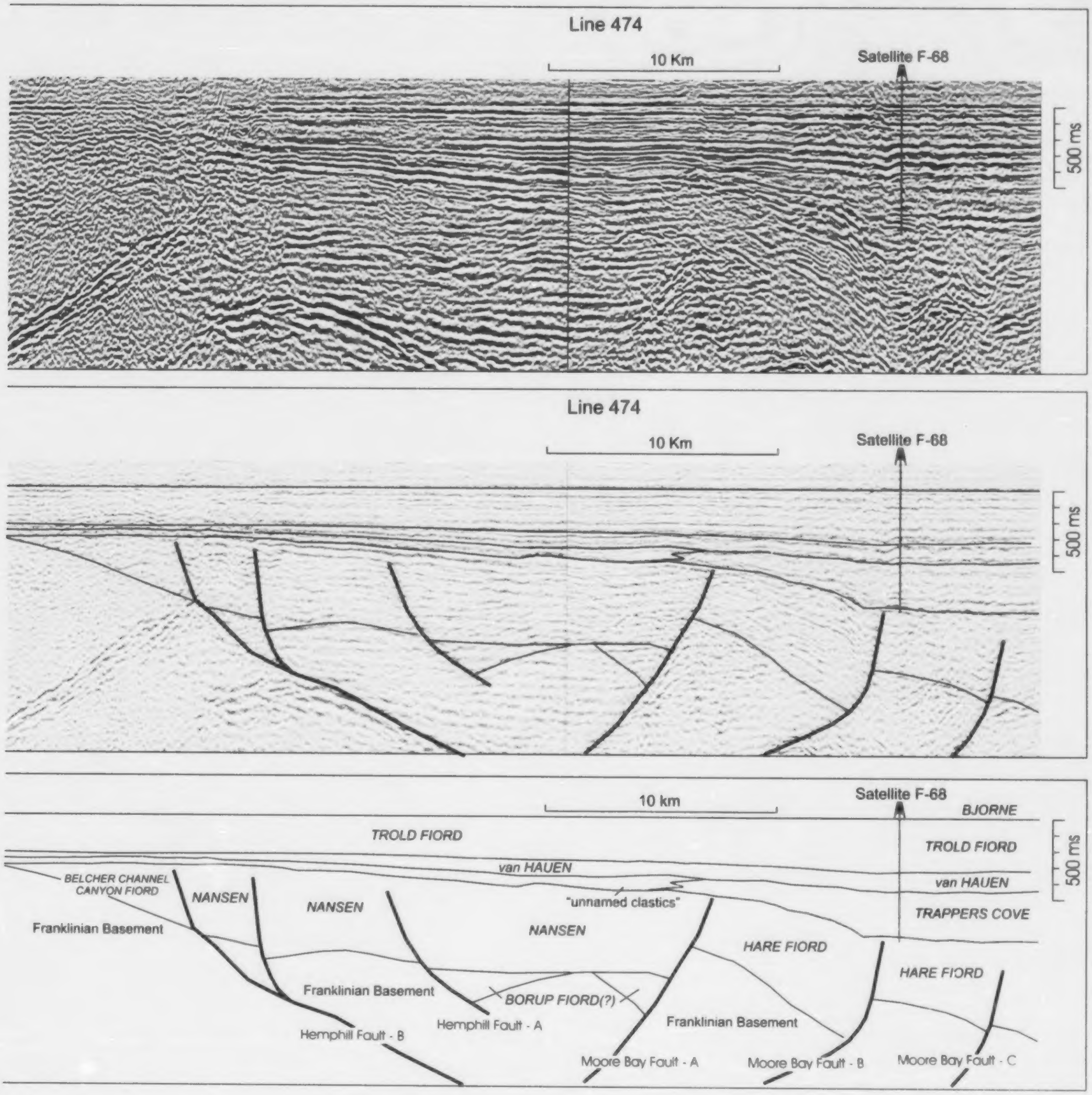

Figure 9. *Composite seismic profile H49-L32-F68 continued.*

occurrence of rare bioclasts (Fig. 10a, c). These include fragments of corals, fusulinaceans, small foraminifers, calcareous algae, brachiopods, bryozoans, echinoderms, and reworked and in situ *Microcodium*. Rare limestone includes variably sandy, pelletal packstone and grainstone with small encrusting foraminifers, echinoderms and *Microcodium* (reworked and in situ) as the dominant components (Fig. 10b).

The gamma-ray signature of the Canyon Fiord Formation displays closely spaced shifts corresponding to high-frequency cycles (Fig. 6), which is typical for the Upper clastic member elsewhere in the Sverdrup Basin. These cycles are expressed in the field as alternating resistant (sandstone, limestone) and recessive (shale) units that impart a typical banded appearance to the upper part of the formation (Thorsteinsson, 1974; Beauchamp, 1987). As

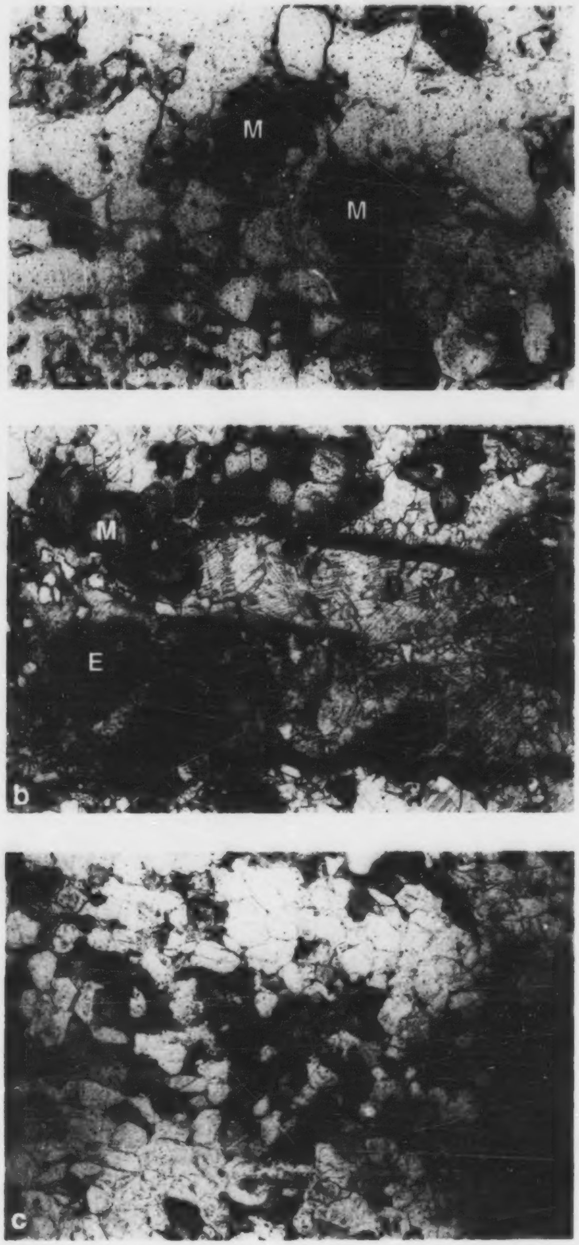

Figure 10. *Photomicrographs of cored interval from Canyon Fiord Formation in Jameson Bay C-31.* ***a.*** *Medium-grained, calcareous sandstone with reworked Microcodium (M). Depth: 7887.5 ft. (2404 m); width of photograph: 1.25 mm; transmitted light.* ***b.*** *Sandy grainstone with reworked Microcodium (M), brachiopods (B) and echinoderms (E). Depth: 7912.5 ft. (2412 ft.); width of photograph: 3.20 mm; transmitted light.* ***c.*** *Medium-grained calcareous sandstone. Depth: 7915.5 ft. (2413 m); width of photograph: 3.20 mm; transmitted light. (GSCC photos 4643-28, 30, 34.)*

many as twenty such cycles, ranging in thickness from 3 to more than 30 m, occur in the Canyon Fiord Formation in Jameson Bay C-31.

A 10 m thick core, recovered 90 m below the top of the formation (7887–7919 ft., 2404–2414 m), displays the upper part of a high-frequency cycle and the lower part of the next overlying cycle (Fig. 11). The lower 20 ft. (6.1 m) of the core (7919–7899 ft., 2414–2408 m) comprises buff-coloured, tabular crossbedded, medium-grained, calcareous sandstone (Fig. 11d) overlain by pinkish, massive, fine-grained, calcareous sandstone. A 6 in. (0.2 m) thick, very coarse grained, pebbly and sandy limestone containing abundant brachiopods, echinoderms, bryozoans, and foraminifers (chambered and encrusting), as well as reworked debris of *Microcodium*, occurs 5 ft. (1.5 m) above the base of the core (Fig. 10b). A large patch of in situ *Microcodium* was found at 7899.5 ft. (2407.5 m). An erosional contact lies at 7899 ft. (2408 m). It is overlain by 9.5 ft. (2.9 m) of deep red shale with abundant caliche nodules (Fig. 11c) in the lower 5 ft. (1.5 m) and thin channel-like siltstone lenses in the upper 5 ft. (1.5 m). Another sharp contact occurs at 7889.5 ft. (2405 m) (Fig. 11b) above which lies pinkish and greenish beige, bioturbated, slightly fossiliferous, fine-grained sandstone.

The basal part of the core represents shoreface deposits, the sharp erosional surface at 7899 ft. (2408 m) is a subaerial unconformity, and the red shale above represents nonmarine floodplain deposits with paleosol development (Fig. 11a). The second sharp surface at 7990 ft. (2435 m) represents a ravinement surface and the uppermost 3 ft. (0.9 m) of the core comprises increasingly marine shoreface deposits (Fig. 11a). The subaerial unconformity at 7899 ft. (2408 m) thus forms a high-frequency sequence boundary, marking the top of a regressive systems tract and the base of a transgressive systems tract. There are twenty or more such high-frequency sequence boundaries in the Canyon Fiord succession penetrated at Jameson Bay C-31.

Seismic expression

The lower part of the Canyon Fiord Formation is seismically transparent, almost reflector-free. Rare, faint reflectors can be outlined in an otherwise homogenous seismic fabric. The upper part of the formation displays better defined, more laterally continuous, divergent reflectors that appear to mimic the cyclic nature of the formation as observed both in the Jameson Bay C-31 well and in the outcrop belts of the southern Sverdrup Basin. Canyon Fiord reflectors dip 3 to 10° in a southwesterly direction toward Jameson Fault-A, John Point Fault, and Hemphill Fault-C (Fig. 8).

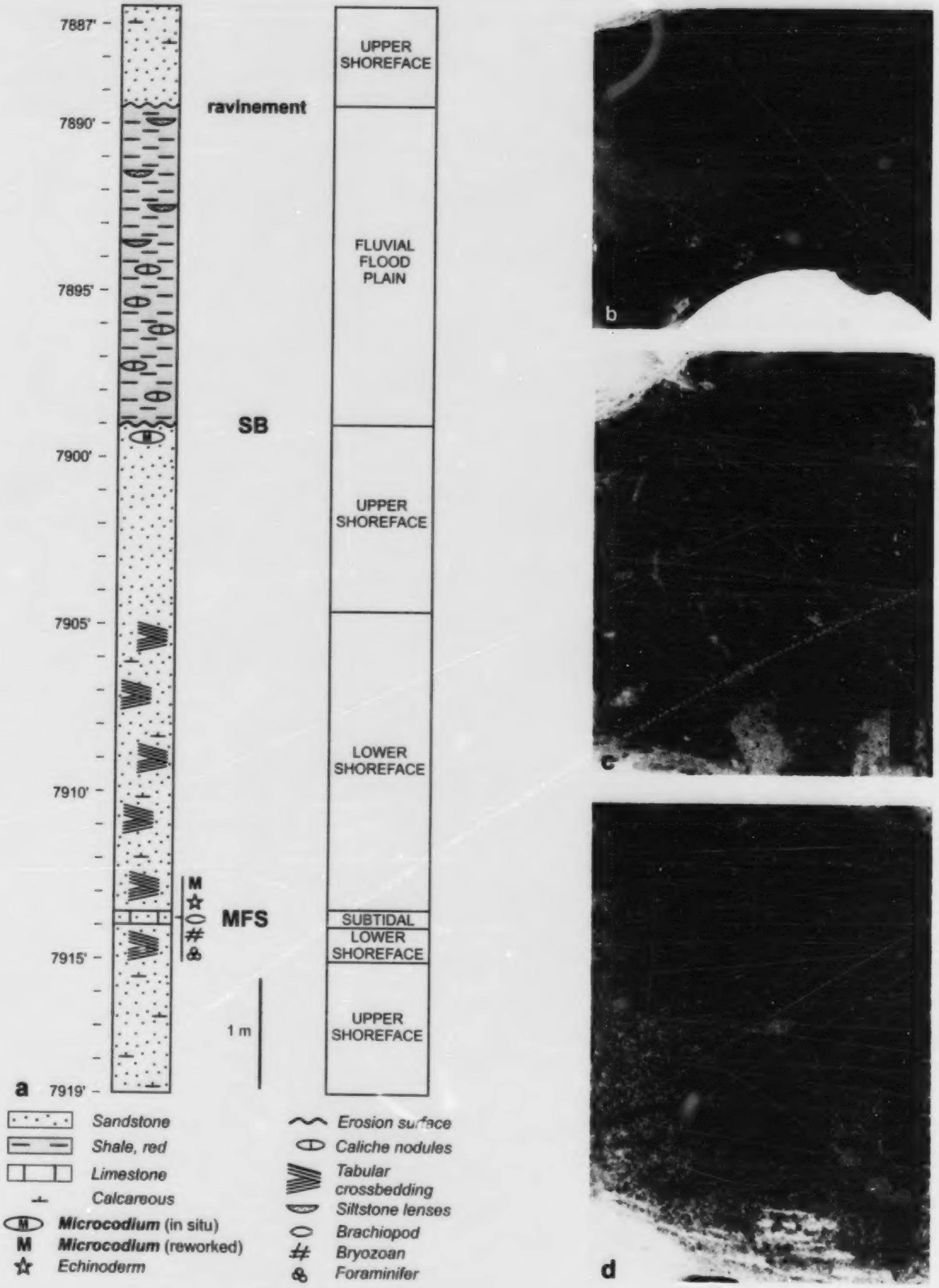

Figure 11. Well core (7886–7919 ft., 2404–2414 m) from Canyon Fiord Formation in Jameson Bay C-31. **a.** Lithological log of core with depositional environments. SB is sequence boundary; MFS is maximum flooding surface. **b.** Ravinement surface between red, nonmarine shale below and marine sandstone above at 7889.5 ft. (2405 m). Scale bar is 5 cm. **c.** Caliche nodules within red, nonmarine shale at 7898.0 ft. (2407 m). Scale bar is 5 cm. d. Crossbedded, calcareous sandstone at 7908 ft. (2410 m). Scale bar is 5 cm. (GSCC photos 4643-6, 5, 3.)

Lower contact

The Canyon Fiord Formation lies with angular unconformity on the Franklinian basement. The bottom of Jameson Bay C-31 is within the upper part of the Upper clastic member (Fig. 6) and lies about 1100 m above the base of the Canyon Fiord Formation (Fig. 8).

Age and correlation

The small foraminifer *Pseudovidalina media*? was recovered from well cuttings selected near the top of the Canyon Fiord Formation (7620–7630 ft., 2323–2326 m) in Jameson Bay C-31 (Fig. 6, Appendix 1). This species is known to range from Gzhelian (latest Carboniferous) to Artinskian (Early Permian) in the Sverdrup Basin (Pinard and Mamet, 1998). The presence of a diagnostic Sakmarian fusulinacean 200 ft. (61 m) above, in the overlying Belcher Channel Formation, excludes the Artinskian from that age range. Upper clastic member strata encountered in Jameson Bay C-31 are thus no older than Gzhelian and no younger than Sakmarian. Elsewhere on Prince Patrick Island, the Canyon Fiord Formation probably ranges from Bashkirian to Sakmarian, which is the entire range of the formation in the Sverdrup Basin in general (Fig. 3; Thorsteinsson, 1974; Beauchamp, 1987), and on nearby Melville Island in particular (Harrison, 1995; Riediger and Harrison, 1993).

Palynological assemblages recovered from the Canyon Fiord Formation (Appendix 1) comprise rare, in situ, medium to dark brown specimens of the Permian *Vittatina vittifera*, associated with a large number of yellow to orange Roadian and Wordian specimens, undoubtedly the product of caving from above.

On Prince Patrick Island, as throughout the Sverdrup Basin, the Canyon Fiord Formation is overlain by and passes into the Belcher Channel Formation (Fig. 6, 8). It is assumed that both units pass laterally into the carbonate-dominated Nansen Formation (Fig. 8) and ultimately into deeper water mudrock of the Hare Fiord Formation as observed in Satellite F-68 (Fig. 6, 8).

Depositional environment

The bulk of the Upper clastic member succession encountered in Jameson Bay C-31 (7710 ft.T.D.; 2350 m) consists of sandstone and shale deposited in an environment that fluctuated from marginal marine to nonmarine. The succession is arranged in a series of high-frequency, subaerial, unconformity-bounded sequences, or cycles, ranging in thickness from 3 to 18 m. The unconformities are sharp erosion surfaces that juxtapose sandstone below and red shale above. The upper part of the sandstone is commonly mottled with patches of *Microcodium*, a postdepositional biodiagenetic encrustration related to subaerial exposure and pedogenesis. The transgressive part of each cycle is represented by the nonmarine red shale that lies above the unconformities. These shales, which display *Microcodium*-bearing caliche nodules and minor sandstone channels, are interpreted as fluvial overbank and floodplain deposits that were subjected to pedogenesis. Above the red shales lie more transgressive strata represented by variably bioturbated, and in places, fossiliferous sandstones. The contact between these sands and the underlying red shales is commonly a sharp ravinement surface. The maximum flooding surface is represented by storm-reworked, variably fossiliferous and bioturbated, shallow subtidal sandstone and limestone. The regressive succession typically comprises buff-coloured, crossbedded to massive, lower to upper shoreface sandstone. The contact between lower shoreface and upper shoreface deposits is usually sharp and erosive.

Both the Middle limestone and Lower clastic members of the Canyon Fiord Formation are believed to occur beneath the Upper clastic member on Prince Patrick Island. Elsewhere in the Sverdrup Basin, the Lower clastic member comprises red conglomerate and sandstone, the bulk of which was deposited during an extensive, basin-wide phase of rifting. These coarse clastic sediments are stream-channel deposits and debris-flows that accumulated in various fault-bounded tectonic depressions in environments ranging from alluvial fans to low-sinuosity braided rivers (Riediger and Harrison, 1993; Beauchamp and Thériault, 1994; Beauchamp et al., 1998). The Middle limestone member commonly consists of variably sandy, fossiliferous marine carbonates stacked in a series of unconformity-bounded, shallowing-upward cycles or high-frequency sequences (Beauchamp, 1987).

Belcher Channel Formation

Definition and type section

The name Belcher Channel Formation was given by Harker and Thorsteinsson (1960) to 240 m of red conglomerate, buff sandstone, grey limestone, greenish grey mixed clastic-carbonate, and yellowish limestone exposed around Lyall River on Grinnell Peninsula, Devon Island. Nassichuk (1965) and Thorsteinsson (1974) removed the basal conglomerate and sandstone from that definition and included them in the Canyon Fiord Formation. Beauchamp and Henderson (1994) formally emended the type section of the Belcher Channel Formation, excluding the upper mixed clastic-carbonate and limestone and including them in the newly erected Raanes and Great Bear Cape formations (see also Beauchamp and Thériault, 1994; and Beauchamp et al., 1998). As a result of these changes to the concept and type section of the formation, the Belcher Channel Formation is now defined as a unit of fossiliferous carbonates that lies above clastic strata of the Canyon Fiord Formation. Only 60 m of Belcher Channel carbonate occur at the type section, but up to 400 m occur along the southern margin of the Sverdrup Basin.

Distribution, thickness, and sonic velocity

The thickness range of the Belcher Channel Formation is unknown on Prince Patrick Island. A 93 m thick interval (7293–7600 ft., 2223–2316.5 m) in Jameson Bay C-31 (Fig. 6) is assigned to the formation. In the more distal areas, where the Belcher Channel Formation could reach a thickness of a few hundreds of metres, the Belcher Channel Formation and the underlying Canyon Fiord Formation cannot be differentiated seismically (Fig. 8). The sonic velocity of the Belcher Channel fluctuates between 12 000 and 18 000 ft./s.

Lithology

At Jameson Bay C-31, the Belcher Channel Formation comprises light grey to greyish brown, fossiliferous, variably sandy limestone, medium to dark grey shale and marlstone, and subordinate fine- to medium-grained, buff sandstone (Fig. 6). Limestone facies are of three kinds. The first is a bioclastic grainstone (Fig.12b) replete with variably abraded and mud-coated debris of echinoderm, brachiopod, bryozoan, fusulinacean, encrusting and chambered small foraminifer, *Palaeoaplysina*, rugose coral, and phylloid, stachein, ungdarellid and dasycladacean algae. In situ patches of *Microcodium* are locally developed. Variably well preserved rinds of fibrous calcite cement followed by sparry calcite cement occlude the primary interparticle porosity. The second includes wackestone and packstone dominated by small, encrusting foraminifers (apterrinellids, tuberetinids, etc.) with locally abundant sponge spicules, stromatactoid sponge cavities, and rare *Palaeoaplysina*, echinoderms and ostracods. The third comprises organic-matter-rich wackestone and packstone (Fig. 12a) with fusulinaceans, bryozoans, echinoderms, and tuberetinid foraminifers as the main components.

Seismic expression

The Belcher Channel Formation cannot be seismically differentiated from the underlying Canyon Fiord Formation. Well-defined, laterally continuous reflectors beneath the Raanes Formation in the hanging wall of John Point Fault and Hemphill Fault-C likely represent carbonates of the Belcher Channel Formation (Fig. 8), but the contact with the underlying Canyon Fiord Formation remains elusive.

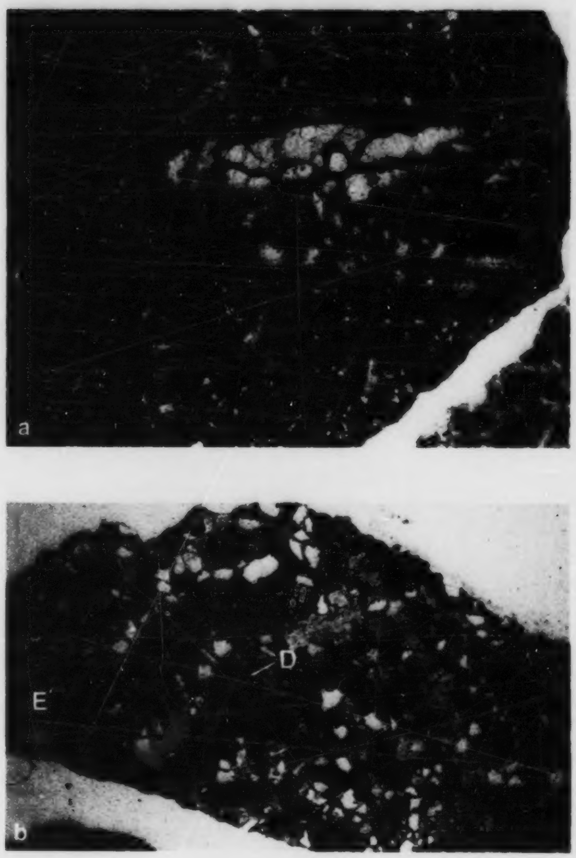

Figure 12. *Photomicrographs of well cuttings from Belcher Channel Formation in Jameson Bay C-31.* ***a.*** *Fusulinacean* ***Eoparafusulina?*** *in bioclastic wackestone. Fine-grained matrix contains sponge spicules and small encrusting foraminifers. Depth: 7410–7430 ft. (2259–2265 m); width of photograph: 2.85 mm; transmitted light.* ***b.*** *Sandy grainstone with echinoderm (E) and dasycladacean alga (D). Depth: 7550–7560 ft. (2301–2304 m); width of photograph: 3.25 mm; transmitted light. (GSCC photos 4643-75, 81.)*

Lower contact

Belcher Channel carbonate and shale rest upon Canyon Fiord sandstone in Jameson Bay C-31. A minor unconformity associated with a high-frequency sequence boundary may occur near or just below the contact. A much sharper contact lies at 7583 ft. (2311 m) just a few metres above the basal formation boundary (Fig. 6). The significance of this contact is discussed under "Sequence stratigraphy". Throughout the Sverdrup Basin, the Canyon Fiord–Belcher Channel contact is highly diachronous (Fig. 3). The same probably holds true in the subsurface of Prince Patrick Island.

Age and correlation

Poorly preserved fusulinacean specimens, broadly indicative of a Late Carboniferous to Early Permian age, were recovered from the 7550–7560 ft. (2301–2304 m) interval in Jameson Bay C-31 (Fig. 6). A single fusulinacean was found in a well cutting gathered from the 7410–7430 ft. (2259–2265 m) interval (Fig. 12a). This specimen, identified by L. Rui (Appendix 1), is similar in general shape, septal folding, and chomata to either *Eoparafusulina*? sp. aff. *E.*? *cheni*, or *Eoparafusulina*? sp. aff. *E.*? *dubius* or *Eoparafusulina*? sp. aff. *E.*? *paraduplex*. These are common Sakmarian markers in the Belcher Channel and Nansen formations on the west and east side of Blind Fiord, southwest Ellesmere Island. An assemblage of small foraminifers from the same interval containing a poorly preserved specimen of *Neohemigordius*? sp. is indicative of a Sakmarian or Artinskian age (Appendix 1).

The Belcher Channel Formation is believed to pass laterally into the Nansen Formation north of Hemphill Fault-B. It is also correlative with the upper part of the Hare Fiord Formation, which was penetrated at the bottom of Satellite F-68 (Fig. 8).

Depositional environment

The bulk of the Belcher Channel succession at Jameson Bay C-31, that is, from the sharp gamma ray kick at 7583 ft. (2311 m) to the top of the uppermost cycle, which is represented by sandstone and minor limestone, is regressive. Superimposed on that regressive trend are a dozen, high-frequency, transgressive–regressive sequences or cycles ranging in thickness from 3 to 12 m. The deeper water part of each cycle consists of calcareous shale, marlstone, and silty and argillaceous wackestone and packstone with bryozoans, echinoderms, brachiopods and fusulinids as the dominant biotic components (Bryonoderm and Bryonoderm-extended assemblages of Beauchamp, 1994 and Beauchamp and Desrochers, 1997). The shallower water part of each cycle comprises variably sandy, algal-rich, bioclastic grainstone and/or encrusting foraminifer-rich wackestone and packstone. Both these high- and low-energy shallow-water facies are represented by Chloroforam biota, which is indicative of tropical conditions (Beauchamp, 1994; Beauchamp and Desrochers, 1997). Some of the cycles are probably bounded by minor unconformities as indicated by the presence of *Microcodium* in a number of well cuttings.

Nansen Formation

Definition and type section

The Nansen Formation is a thick unit of carbonate strata that outcrop widely on Ellesmere and Axel Heiberg islands (Fig. 3). It was defined by Thorsteinsson (1974) who erected the type section at Girty Creek, near the head of Hare Fiord, northwest Ellesmere Island. Over 2 km of variably fossiliferous, reefal carbonate have been measured, constituting the thickest occurrence of the formation ever recorded in the Sverdrup Basin. Beauchamp and Henderson (1994) emended the original definition of the formation to exclude strata contained in its upper part. These strata, of Sakmarian and Artinskian age, are now part of the Raanes and Great Bear Cape formations. Nansen carbonate rests atop either the Franklinian basement, Borup Fiord redbeds, or Hare Fiord mudrock. Light-coloured Nansen strata pass basinward into dark-coloured Hare Fiord mudrock, and cratonward into clastic and carbonate rocks of the Canyon Fiord and Belcher Channel formations, or clastic, carbonate and evaporite strata of the Antoinette, Mount Bayley, and Tanquary formations (Fig. 3).

Distribution, thickness, and sonic velocity

The Nansen Formation is arbitrarily assigned to a thick seismic unit that lies stratigraphically above the Borup Fiord Formation and below the Raanes Formation between Hemphill Fault-B and Moore Bay Fault-A (Fig. 8, 9). The unit is between 500 and 700 ms thick, which translates into an average thickness of about 1.5 km.

Lithology

The unit assigned to the Nansen Formation is believed to comprise carbonate and subordinate clastic rocks (sandstone, shale) arranged in a series of high-frequency, shallowing-upward cycles, locally associated with variably large carbonate buildups. These assumptions are based on: 1) the position of the Nansen Formation between drilled clastic and carbonate rocks of the Canyon Fiord and Belcher Channel formations to the south (Jameson Bay C-31, Fig. 6) and drilled mudrock of the Hare Fiord Formation to the north (Satellite F-68); 2) the occurrence of fossiliferous shelf- and shelf-margin-derived carbonate debris within the Hare Fiord Formation at Satellite F-68; and 3) comparisons with the known lithological content and paleogeographic position of the Nansen Formation elsewhere in the Sverdrup Basin (Thorsteinsson, 1974; Beauchamp, 1987; Morin et al., 1994; Beauchamp et al., 1995a, c).

The twofold seismic expression of the Nansen Formation suggests that basic lithological differences, such as the clastic content, may exist between the lower and upper parts of the formation.

Seismic expression

The unit comprises a series of laterally continuous, well-defined reflectors in its upper part, and a more transparent, reflector-free succession in its lower part. The signal is increasingly blurred by strong multiples toward the north, that is, in the deepest areas.

Lower contact

The Nansen Formation rests unconformably upon the Franklinian basement or the Borup Fiord Formation.

Age and correlation

Bashkirian to Sakmarian fossils (Fig. 3) have been recovered from the Nansen Formation in the mountain exposures of Ellesmere and Axel Heiberg islands (Thorsteinsson, 1974; Nassichuk and Wilde, 1977; Rui et al., 1991; Groves et al., 1994; Pinard and Mamet, 1998).

Depositional environment

Throughout the Sverdrup Basin, the Nansen Formation records shelf to shelf-margin cyclic carbonate deposition, and the same depositional environment is assumed to be recorded on Prince Patrick Island. The well-defined, laterally continuous reflectors in the upper part of the formation are reminiscent of the typical, recessive–resistant banded appearance of the formation in the outcrop belt (Beauchamp, 1987; Beauchamp et al., 1995c). The occurrence of a wide variety of shallow- to deep-water, shelf-derived carbonate debris in the more distal Hare Fiord Formation attests to the presence of an active carbonate factory updip from Satellite F-68. Some of the debris was derived from carbonate buildups, providing additional evidence for the presence of typical shelf and shelf-margin carbonates a few kilometres upslope.

Hare Fiord Formation

Definition and type section

The name Hare Fiord Formation was given by Thorsteinsson (1974) to a thick unit of basin-axial, dark-coloured mudrocks (shale, argillaceous limestone, chert) correlative with carbonates of the Nansen Formation. The original type section of the formation, erected just north of van Hauen Pass, northwest Ellesmere Island, contained more than 750 m of limestone (breccias, debris flows), turbiditic argillaceous limestone, and calcareous siltstone, chert and shale. The upper 370 m of the type section, a recessive shale unit overlain by cliff-forming, spiculitic chert, were recently assigned to the Artinskian Trappers Cove Formation (Beauchamp and Henderson, 1994), the basinal equivalent of the Great Bear Cape Formation.

The deep-water, basin-axial Moscovian to Sakmarian Hare Fiord Formation passes landward and upward into the shallow-water, basin-marginal Nansen Formation. A prominent Upper Carboniferous tongue of the Hare Fiord Formation, which extends a fair distance landward, splits the shallow-water Nansen carbonate succession into two units. Where this occurs, the upper carbonate still belongs, by definition, to the Nansen Formation, whereas the lower carbonate constitutes a different stratigraphic unit to be defined in a future publication (Fig. 3). Elsewhere, the Hare Fiord Formation rests directly upon evaporites of the Otto Fiord Formation, the upper parts of which are Atokan to early Desmoinesian in age, based on foraminiferal identification of Mamet (*in* Nassichuk and Davies, 1980), and not older than Bashkirian, based on palynomorphs (Utting, 1985).

Distribution, thickness, and sonic velocity

More than 94 m of dark-coloured mudrock and minor carbonate (11 765 ft. T.D.; 3586 m) belonging to the Hare Fiord Formation were encountered at the bottom of Satellite F-68 (Fig. 6, 7). These rocks have a sonic velocity ranging from 15 000 to 18 000 ft./s. The Hare Fiord Formation is 400 ms thick at that locality. It thickens to more than 600 ms locally, which translates into a thickness of more than 1300 m. The thickness of the Hare Fiord Formation varies over relatively short distances as a result of Carboniferous and Permian faulting. The Hare Fiord Formation is believed to pass laterally into carbonate of the Nansen Formation in the vicinity of Moore Bay Fault-A (Fig. 8, 9).

Lithology

The Hare Fiord Formation at Satellite F-68 comprises medium brownish grey, organic-matter-rich, variably calcareous, silty shale with subordinate amounts of limestone and calcareous chert (Fig. 6, 7). The limestone forms discrete units within the otherwise shaly and silty surroundings. These units comprise a wide variety of unrelated carbonate facies, suggesting that many are derived from the lithic fragments of various breccias (Fig. 13). The sampled cuttings yielded pieces of variably shaly and silty bryozoan-brachiopod-echinoderm wackestone, packstone and grainstone, phylloid algal-stromatactoid wackestone, and bryozoan-phylloid algal grainstone and packstone, as well as large fragments of rugose corals.

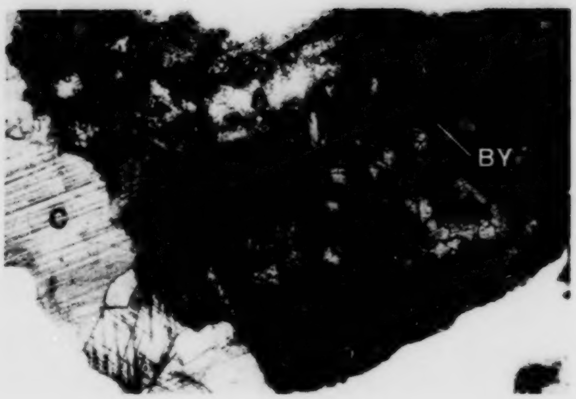

Figure 13. Photomicrograph of well cutting from Hare Fiord Formation in Satellite F-68. Reef-derived wackestone-packstone with phylloid alga (A), fenestellid bryozoan (BY), and spar-cemented open-space cavitiy (C). Depth: 12 050–12 075 ft. (3673–3680 m); width of photograph: 3.25 mm; transmitted light. (GSCC photo 4643-104.)

Seismic expression

The Hare Fiord Formation displays a series of laterally discontinuous inclined reflectors dipping up to 15° toward Moore Bay Fault-B and -C (Fig. 8, 9). Interference with multiples hinders the primary signal in the more distal area.

Lower contact

There are no direct observations of the basal contact of the Hare Fiord Formation because Satellite F-68 bottomed hundreds of metres above the base of the formation. There is a possibility that evaporites of the Otto Fiord Formation may be present beneath the northernmost areas of Prince Patrick Island. Alternately, and in view of the absence of evaporite diapirs on northern Prince Patrick Island, Hare Fiord mudrock may rest on carbonate, as observed in other areas of the Sverdrup Basin (Fig. 3; Thériault et al., 1995b). In either case, the contact between the Hare Fiord Formation and the underlying unit is likely conformable.

Age and correlation

One specimen of either "*Frondicularia*"? sp. or *Geinitzina*? sp. was recovered from well cuttings gathered from the 12 050–12 075 ft. (3673–3680 m) interval (Appendix 1). This small foraminifer is loosely indicative of a Sakmarian or younger Permian age. However, the presence of dissolved algae (dasycladaceans?, phylloids?) in the sample that contains this specimen narrows its age range to Sakmarian–early Artinskian, for such algae do not occur in the Sverdrup Basin in Artinskian or younger rocks (Beauchamp, 1994; Beauchamp and Desrochers 1997; Beauchamp and Henderson, 1994).

Sequence stratigraphic correlations, discussed later in this chapter, suggest that most of the 94 m of mudrock assigned to the upper Hare Fiord Formation in Satellite F-68 are correlative with the Raanes Formation in Jameson Bay C-31 (Fig. 6). However, the bulk of the Hare Fiord Formation on northern Prince Patrick Island is believed to be correlative with the Nansen Formation south of Moore Bay Fault-A and with the Canyon Fiord–Belcher Channel couplet south of Hemphill Fault-B (Fig. 3).

Depositional environment

The 94 m of Hare Fiord mudrock in Satellite F-68 were deposited in a distal, deep-water slope setting that received occasional carbonate debris flows and turbidites from a nearby shelf against a background sedimentation of organic-matter-rich, fossil-free, silty mud. As suggested by previous studies throughout the Sverdrup Basin, the bryozoan-brachiopod-echinoderm packstone and grainstone are likely grainy turbidite, whereas the wide variety of other carbonate facies are from carbonate breccia. Among the clasts observed are carbonate buildup facies (stromatactoid-phylloid algal wackestones) attesting to the presence of reefal constructions upslope near the shelf edge.

Raanes Formation

Definition and type section

The Raanes Formation was defined by Beauchamp and Henderson (1994) as a unit of shale; siltstone; moderately fossiliferous, argillaceous, and silty limestone; and mixed clastic-carbonate and fossiliferous limestone that overlies either the Canyon Fiord, Belcher Channel, Tanquary, or Nansen formations at the margin of the Sverdrup Basin (Fig. 3). The type section of the Raanes Formation is located northeast of the head of Blind Fiord, on Raanes Peninsula, southwest Ellesmere Island, where it comprises 167 m of the above mentioned lithologies.

Distribution, thickness, and sonic velocity

A 52 m thick interval with a sonic velocity of between 12 000 and 18 000 ft./s in Jameson Bay C-31 (7120–7293 ft., 2170–2223 m) is attributed to the Raanes Formation (Fig. 6). The Raanes Formation has an irregular distribution in the hanging walls of Jameson Fault-A, John Point Fault, and

Hemphill Fault-C, where it ranges from a feather edge to as much as 140 ms or approximately 300 m (Fig. 8). The Raanes Formation pinches out beneath the 'unnamed clastics' unit between Hemphill Fault-A and Moore Bay Fault-A (Fig. 8).

Lithology

The Raanes Formation in Jameson Bay C-31 is composed of shale, siltstone, sandstone, mixed clastic-carbonate, and limestone. The shale and siltstone are light to dark grey and variably calcareous. The mixed clastic-carbonates and limestone are buff to brownish grey, and are variably sandy and silty. Some of the carbonate facies observed in rock cuttings include: brachiopod-echinoderm grainstone (Fig. 14); brachiopod-echinoderm small foraminifer-algal (dasycladacean?, phylloid?) grainstone (Fig. 14a); and fusulininacean-echinoderm-encrusting foraminifer-algal (stachein) packstone. The sandstone is fine to medium grained and composed of subangular quartz and chert grains, the latter ranging in proportion from 5 to 20%.

Seismic expression

The Raanes Formation is attributed to a seismically transparent unit that contrasts with the strong reflectors observed in the underlying Canyon Fiord–Belcher Channel couplet (Fig. 8). Faint reflectors can be observed within the Raanes Formation.

Lower contact

The unconformable contact between the Raanes Formation and the underlying Belcher Channel Formation in Jameson Bay C-31 is marked by a change in the gamma-ray signature as closely spaced, carbonate-dominated, high-frequency cycles of the Belcher Channel Formation give way to more widely spaced cycles of the Raanes Formation, which is dominated by shale, siltstone, mixed clastic-carbonate and subordinate carbonate (Fig. 6). This contact appears angular immediately north of Hemphill Fault-C, where faint reflectors attributed to the Raanes Formation appear to onlap the assumed upper surface of the Belcher Channel in a northerly direction (Fig. 8).

Age and correlation

A prolific assemblage of small foraminifers was recovered from rock cuttings sampled in the 7220–7230 ft. (2201–2204 m) interval at Jameson Bay C-31 (Appendix 1). Key specimens include *Nodoisinelloides*? *gracilis*, *N.*? *longa*, *Asselodiscus primitivus*, and *Geinitzina* sp. In the Sverdrup Basin, *Nodoisinelloides* ranges from early Kasimovian to Artinskian, but it is most abundant in the Sakmarian, and seemingly absent in upper Artinskian rocks. *Geinitzina* is no older than Sakmarian in the Sverdrup Basin, but ranges well into the Artinskian and possibly into younger rocks. *Asselodiscus primitivus* has not yet been identified in rocks younger than Artinskian. This association, in addition to the possible occurrence of "*Frondicularia*", is indicative of a Late Sakmarian to Early Artinskian age.

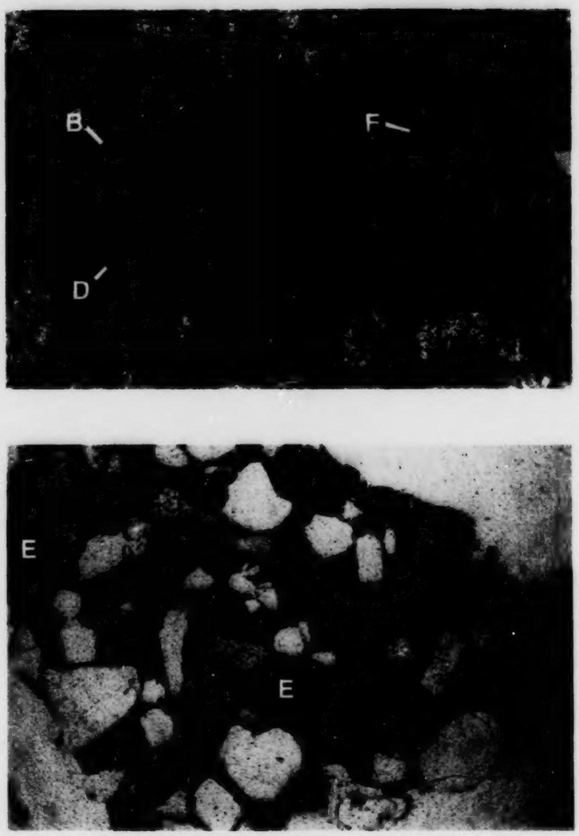

***Figure 14.** Photomicrographs of well cuttings from Raanes Formation in Jameson Bay C-31. **a.** Bioclastic grainstone with variably dissolved dasycladacean alga (D), brachiopod (B) and geneitzinid foraminifer (F). Depth: 7220–7230 ft. (2201–2204 m); width of photograph: 1.27 mm; transmitted light. **b.** Sandy echinoderm (E) grainstone. Depth: 7160–7170 ft. (2182–2185 m); width of photograph: 2.95 mm; transmitted light. (GSCC photos 4643-74, 69.)*

Based on conodont fauna, Beauchamp and Henderson (1994) considered the Raanes Formation to be of Early Artinskian (Aktastinian) age. However, recently published data based on fusulinaceans and colonial corals (Beauchamp et al., 1998; Bamber and Fedorowsky, 1998) have suggested that a substantial portion, if not all, of the Raanes Formation might be of Sakmarian age. A series of paleontological studies are under way to clarify this discrepancy.

In situ pollen taxa from the 7230–7280 ft. (2204–2219 m) interval include rare *Vittatina* sp. and *Protohaploxypinus* sp. A associated with abundant Roadian taxa, undoubtedly caved from above (Appendix 1).

Depositional environment

The Raanes Formation in Jameson Bay C-31 comprises shale and siltstone at the base passing upward into mixed clastic carbonate, packstone, sandy grainstone and calcareous sandstone. These beds represent low- to high-energy, open-marine, subtidal shelf or ramp deposits. The upper surface of the Raanes Formation appears to onlap against an elevated body between Hemphill Fault-A and Moore Bay Fault-A (Fig. 8). These relationships may well indicate the presence of a reef in that area, an interpretation congruent with similar reefal occurrences at that stratigraphic level throughout the Sverdrup Basin. Reefs in the Raanes Formation are mud mounds characterized by a sponge–bryozoan biota (Beauchamp, 1989, 1993).

'Unnamed clastics' formation

Definition and type section

The unit herein referred to as the 'unnamed clastics' formation occupies the same stratigraphic interval and paleogeographic position as the Great Bear Cape Formation, but differs from the latter by being almost exclusively composed of sandstone and shale, with very little, if any, carbonate material. The Great Bear Cape Formation is a unit of fossiliferous carbonate that lies above the Raanes Formation along the southern and northern margins of the Sverdrup Basin (Fig. 3). The Great Bear Cape Formation was defined by Beauchamp and Henderson (1994), who erected the 148 m thick type section from the same area as the type Raanes Formation, a few kilometres northeast of the head of Blind Fiord, southwest Ellesmere Island. The Great Bear Cape Formation is overlain by either the Sabine Bay, Esayoo, Assistance, van Hauen, or Trold Fiord Formation.

Sandstone and red shale do occur locally as subordinate lithologies within the Great Bear Cape Formation and can be locally abundant near the erosional edge of the formation (Beauchamp and Henderson, 1994; Scott, 1992). In those instances, however, Great Bear Cape-correlative clastic strata pass basinward into typical Great Bear Cape carbonate over a short distance. Nowhere are Great Bear Cape-correlative coarse clastic sediments and associated red shale more abundant and more geographically extensive than on Prince Patrick Island, where an area of over 3500 square kilometres is covered by up to 250 m of clastic sediments that pass directly into correlative deep-water mudrock of the Trappers Cove Formation with no intermediate occurrences of carbonate. By themselves, these findings could warrant the erection a new stratigraphic unit, but the authors prefer gathering additional information about the regional extent of the formation, as well as finding a more suitable type section, before formalizing a new unit.

Distribution, thickness, and sonic velocity

At Andreasen L-32, the 'unnamed clastics' formation was assigned to a 62 m thick sandstone-dominated unit (6845 ft.; 2086 m to T.D.) that lies between the Franklinian basement and the van Hauen Formation (Fig. 7). These strata display a wide-ranging sonic velocity of 13 000 to 18 000 ft./s. The 'unnamed clastics' formation could reach a maximum thickness of 100 ms (about 250 m) near its lateral transition to the correlative Trappers Cove Formation. This lateral facies change is believed to take place just south of Moore Bay Fault-A (Fig. 9).

Lithology

At Andreasen L-32, the 'unnamed clastics' formation is dominated by variably conglomeratic sandstone, rare chert pebble conglomerate, red siltstone and shale, and dark grey shale. Terrigenous sand grains are composed of quartz and chert, with the latter locally occurring in proportions of up to 40 per cent (Fig. 15).

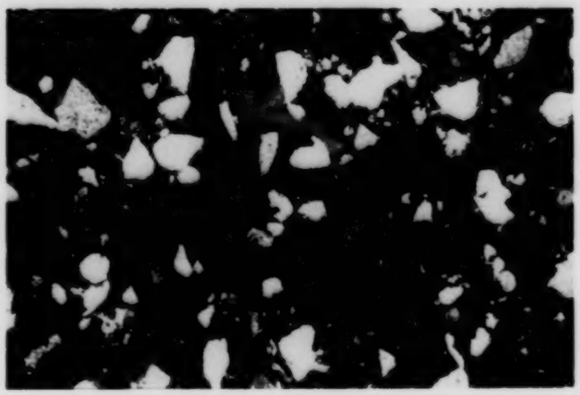

Figure 15. *Photomicrograph of well cutting from 'unnamed clastics' formation, Andreasen L-32. Poorly sorted fine- to medium-grained sandstone. Uniformly white, grey and black grains are quartz. All other mottled grains are chert. Depth: 6930–6940 ft. (2112–2115 m); width of photograph: 3.35 mm; crossed nichols.*

Seismic expression

The 'unnamed clastics' formation is a nearly reflector-free, transparent unit that can be traced laterally into the more reflective Trappers Cove Formation.

Lower contact

The 'unnamed clastics' formation lies unconformably upon the Franklinian basement at Andreasen L-32, and either disconformably or conformably on the Belcher Channel, Nansen and Raanes formations in the more distal areas. Truncation of seismic reflectors between Hemphill Fault-C and -B (Fig. 8) suggests that the 'unnamed clastics' formation lies with an angular unconformity on the Belcher Channel Formation in that area.

Age and correlation

No age-diagnostic fossils were recovered from the 'unnamed clastics' formation on Prince Patrick Island. The unit is considered to be Artinskian based on its physical correlation with the Trappers Cove Formation. The Great Bear Cape Formation is Artinskian in age based on several fossil groups (Beauchamp and Henderson, 1994).

Depositional environment

The 'unnamed clastics' formation comprises a widespread blanket of clastic rocks that were deposited in a variety of environments ranging from fluvial to relatively deep offshore ramp. At Andreasen L-32, the presence of red shale and pebbly sandstone suggests an environment shifting from nonmarine to marginal marine (shoreface) conditions. Strata reflecting more open-marine conditions undoubtedly characterize the 'unnamed clastics' formation in the more distal areas. The lack of clinoforms along the lateral transition between the 'unnamed clastics' and the Trappers Cove formations suggests a ramp-like passage from the sandstone-dominated environments of the former into the shale- and siltstone-dominated environments of the latter. No shelf break can be recognized along that transition.

Trappers Cove Formation

Definition and type section

The Trappers Cove Formation was defined by Beauchamp and Henderson (1994) as a unit of dark-coloured mudrocks (shale, siltstone, chert, minor limestone) that occurs widely in the axial regions of the Sverdrup Basin, where it lies above the Hare Fiord Formation and beneath the van Hauen Formation. The Trappers Cove Formation extends for some distance cratonward where it sits between the Raanes and Great Bear Cape formations. The type section of the Trappers Cove Formation, 214 m of shale, chert, and minor limestone, is located immediately west of the head of Blind Fiord, southwest Ellesmere Island.

Distribution, thickness, and sonic velocity

A 595 m thick unit of shale and siltstone is attributed to the Trappers Cove Formation in Satellite F-68 (9800–11 765 ft., 2987–3586 m), which is near the thickest occurrence of the formation on Prince Patrick Island. From that well (Fig. 6, 7), the formation thins both to the northeast and to the southwest as it passes into the correlative 'unnamed clastics' formation between Moore Fault-A and Hemphill Fault-A (Fig. 8, 9). A wide range of sonic velocities was measured in the Trappers Cove Formation in Satellite F-68, from 7000 ft./s near the base to 18000 ft./s near the top.

Lithology

The Trappers Cove Formation at Satellite F-68 is composed of dark brownish grey to black, organic matter- and pyrite-rich, faintly calcareous shale, silty shale, mudstone and shaly siltstone (Fig. 6, 7). The darkest, finest and most organic-rich material occurs at the base of the formation (Fig. 16b). Extremely rare sponge spicules, tiny agglutinated foraminifers, bryozoans, and brachiopods are the only fossils observed.

A 5.5 m core was retrieved from the 10 458–10 476 ft. (3188–3193 m) interval. It consists of organic matter-rich, pyritic, calcareous silty shale in the lower 11 ft. (3.4 m), and calcareous shaly siltstone in the upper 7 ft. (2.1 m) (Fig. 16a). The subtle lithological change at 10 465 ft. (3190 m) is marked by a rather abrupt shift in the gamma-ray log, which may or may not be indicative of a change in organic matter content at this level. Similar sharp kicks in the gamma-ray log occur throughout the Trappers Cove Formation (Fig. 6, 7), but as in the core, they are not indicative of any major lithological change. Rare fossils in the core comprise tiny brachiopod fragments, complete brachiopod valves, and fenetellid bryozoan debris. Two kinds of horizontal burrows occur throughout the core. The first kind consists of 2–3 mm wide black strings, which represent a section of flattened, worm-like burrows as seen in plan view. The second type, which consists of larger burrows, 3 to 10 mm in diameter, displays internal arcuate laminae.

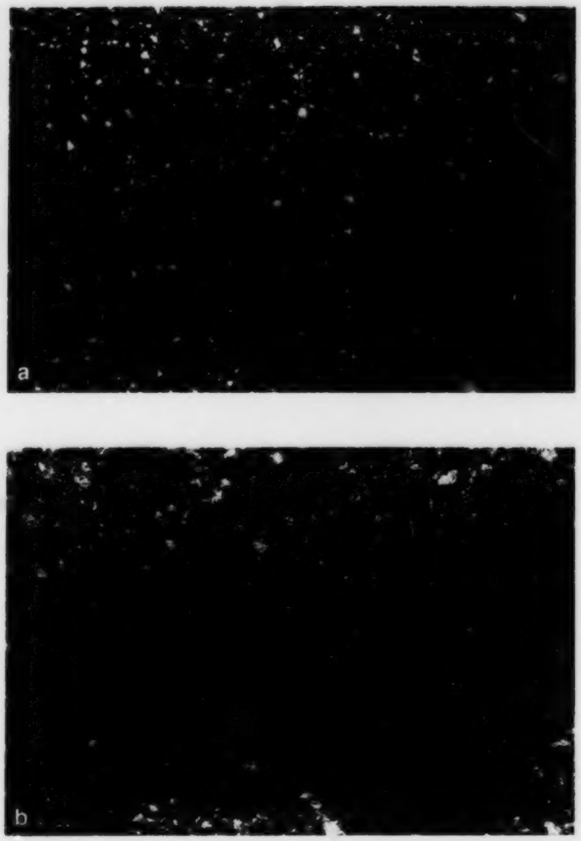

Figure 16. *Photomicrographs of well core (**a**) and cutting (**b**) from Trappers Cove Formation in Satellite F-68.* ***a.*** *Dark, shaly siltstone. Depth: 10 473 ft. (3192 m); width of photograph: 3.20 mm; transmitted light.* ***b.*** *Dark, organic-matter- and pyrite-rich silty shale. Black stringers are either pyrite or organic matter. Depth: 11 310–11 320 ft. (3447–3450 m); width of photograph: 1.25 mm; transmitted light. (GSCC photos 4643-45, 100.)*

Seismic expression

The Trappers Cove Formation is less transparent seismically than its correlative the 'unnamed clastics' formation. A series of relatively continuous reflectors that appear to onlap the underlying Hare Fiord Formation are present at the base of the formation. A more transparent, reflector-free succession is displayed in the upper part of the formation, which contrasts with the strongly reflective units in the overlying van Hauen and Trold Fiord formations (Fig. 8, 9).

Lower contact

The Trappers Cove Formation rests conformably to unconformably upon the Hare Fiord Formation and probably upon the Nansen Formation locally (Fig. 8, 9). The contact between the two formations is indicated by a sharp shift on the gamma-ray log corresponding to a dramatic increase in organic matter content in the basal Trappers Cove shale (Fig. 6, 7).

Age and correlation

No age-diagnostic fossils were recovered from the Trappers Cove Formation. The presence of late Sakmarian or Artinskian foraminifers in the underlying Hare Fiord Formation in Satellite F-68 and the occurrence of Roadian and Wordian palynomorphs in the overlying van Hauen Formation suggest an Artinskian to Kungurian age for the Trappers Cove Formation, which is the age of the formation elsewhere in the Sverdrup Basin (Beauchamp and Henderson, 1994).

Depositional environment

The Trappers Cove Formation in Satellite F-68 contains fine-grained strata deposited in a distal, deep-marine, suboxic environment that ranged from basinal at the base to gently dipping slope at the top. The absence of inclined clinoforms on seismic profiles suggests a ramp-like transition between the shallow environments to the southwest and the deep settings to the northeast. Furthermore, the absence of chert and carbonate in the Trappers Cove Formation reflects the fact that upslope ramp deposits were clastic-dominated ('unnamed clastics' formation).

Sabine Bay Formation

Definition and type section

The name Sabine Bay Formation was first given by Tozer and Thorsteinsson (1964) to a relatively thin (120 m or less) succession of light coloured, nonmarine, quartzose sandstone that outcrops on Sabine Peninsula, Melville Island, where it rests upon carbonates of the Great Bear Cape Formation (formerly Belcher Channel Formation; Harrison, 1995; Beauchamp and Henderson, 1994). In addition to its Melville Island occurrence, the Sabine Bay Formation outcrops irregularly along the southern and northern margins of the Sverdrup Basin (Thorsteinsson, 1974).

Distribution, thickness, and sonic velocity

The Sabine Bay Formation forms a 134 m thick interval (6680–7120 ft., 2036–2170 m) in Jameson Bay C-31 (Fig. 6), where it lies between the 'unnamed clastics' and the van Hauen formations. The Sabine Bay Formation has a limited geographic distribution north, south, and west of John Point Fault. The formation abuts against Jameson Fault-A and thins to zero over an anticlinal structure that lies between Jameson Fault-A and John Point Fault (Fig. 8). The formation reaches a maximum thickness of about 350 m (180 ms) just south of John Point Fault. The sonic velocity of the Sabine Bay Formation at Jameson Bay C-31 clusters between 12 000 and 16 000 ft./s.

Lithology

The Sabine Bay Formation comprises two basic lithologies: red shale and buff sandstone. Red, silty shale, associated with minor, fine-grained, red sandstone is the dominant lithology in the lower 89 m (6830–7120 ft., 2081–2170 m) in Jameson Bay C-31 (Fig. 6). Buff sandstone constitutes the main lithology in the upper 45 m of the formation, associated with chert and limestone pebble conglomerate (Fig. 17), and thin, dark grey shale horizons. The sandstone is fine to very coarse grained, very angular to subangular, poorly sorted, and locally conglomeratic, with pebble-sized, multicoloured, variegated chert clasts and grey limestone clasts, some of which are micritized. Abraded remnants of large fusulinids are also present (Fig. 17). Sand grains consist of up to 50 per cent chert fragments. Some of the sandstone is calcareous as a result of the presence of interparticle carbonate cement and, less commonly, locally derived micritized and iron oxide-stained carbonate grains. Rare, red-stained, echinoderm ossicles can be recognized.

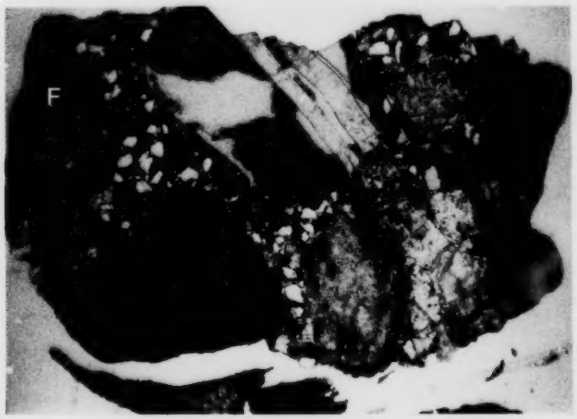

Figure 17. *Photomicrograph of well cutting from Sabine Bay Formation, Jameson Bay C-31. Chert- and limestone-pebble sandy conglomerate. Limestone grains include micritized fusulinacean (F). Depth: 6970–6980 ft. (2124–2127 m); width of photograph: 5.8 mm; transmitted light. (GSCC photo 4643-68.)*

Seismic expression

The Sabine Bay Formation, as shown in Figure 8, shows a few widely spaced reflectors in its lower part north and south of John Point Fault, whereas the upper part is transparent and reflector-free.

Lower contact

The Sabine Bay Formation rests unconformably on either the Raanes (Jameson Bay C-31), the Belcher Channel, or the Canyon Fiord Formation (Fig. 6, 8).

Age and correlation

Rock cuttings from the 6780–6810 ft. (2067–2075 m) interval (Appendix 1) yielded an abundant palynological assemblage that correlates well with the *Alisporites plicatus–Jugasporites compactus* Concurrent Range Zone (Utting, 1994). A Roadian age has been assigned to this palynological zone based largely on ammonoids recovered from the Sabine Bay and Assistance formations (Utting, 1994), including the ammonoid *Sverdrupites* sp. near the base of the Sabine Bay Formation on Melville Island (Nassichuk, 1995). This age assignment reflects a former correlation with the Road Canyon Formation, west Texas, the whole of which was viewed as the stratotype of the Roadian Stage (Furnish, 1973).

There is a possibility, however, that a substantial portion, if not all, of the Sabine Bay Formation may be Kungurian in age. This suggestion is based on the first appearance of serrated gondolellid conodonts about one third of the way through the Assistance Formation on Ellesmere Island (C.M. Henderson, pers. comm., 1999). The base of the Assistance, which overlies the Sabine Bay Formation, includes *Mesogondolella idahoensis*. Overlying this fauna is an assemblage of *Mesogondolella idahoensis* and *M. gracilis*, including rare serrated forms. The first appearance of serrated gondolellid conodonts is broadly viewed as marking the base of the Roadian (basal Guadalupian) throughout the world (Mei et al., 1999).

In addition, a Kungurian conodont assemblage comprising *Neostreptognathodus pnevi* and *N. ruzhencevi* was recovered in the lower part of the Sabine Bay Formation at Mount Bridgeman, west-central Elllesmere Island (Henderson, pers. comm., 1999). These findings suggest that, based on conodonts, the entire Sabine Bay Formation is of Kungurian age on Ellesmere Island and presumably on Prince Patrick Island as well (Fig. 6). This age assignment is congruent with a more recent age interpretation for the Road Canyon Formation of West Texas, whereby a substantial portion of the formation is correlated with the Kungurian Stage of Russia. Only the upper part of the Road Canyon Formation now represents the Roadian Stage (Jin et al., 1997).

Depositional environment

The Sabine Bay succession in Jameson Bay C-31 is very similar to that observed at many localities on Hamilton Peninsula, west-central Ellesmere Island, where a variably thick red shale unit, representing fluvial floodplain deposits in a semiarid setting, is overlain by buff sandstone and channeled chert- and limestone-pebble conglomerate interfingering with thin, dark grey to black coaly shale, representing fluvial to marginal marine estuarine deposits in a much more humid setting. The contact between the buff sandstone and the red shale is almost invariably erosive and represents a ravinement surface. In Jameson Bay C-31, the abundance of spores and pollen with rare acritarchs in the palynological samples recovered from the buff sandstone unit is also suggestive of a shallow-nearshore marine environment of deposition for at least the shale that was sampled. The presence of fungal spores in the upper Sabine Bay suggests a humid climate. Pervasive red coloration in the lower Sabine Bay may be indicative of arid conditions.

Van Hauen Formation

Definition and type section

The van Hauen Formation is a unit of dark grey to black shale, siltstone and chert, and subordinate yellowish- to greenish-grey weathering limestone and sandstone that occurs widely in the axial regions of the Sverdrup Basin. The type section of the formation was erected at van Hauen Pass, northwest Ellesmere Island (Thorsteinsson, 1974), where 400 m of dark mudrock lie between the Trappers Cove Formation and the Degerböls Formation.

Distribution, thickness, and sonic velocity

On Prince Patrick Island, the van Hauen Formation forms a wedge that thickens from a feather edge just south of Jameson Bay C-31 and Andreasen L-32 to probably more than 500 m to the northeast (Fig. 8, 9). The formation was encountered in three wells (Fig. 6, 7): it is 155 m (80 ms) thick in Jameson Bay C-31 (6172–6680 ft., 1881–2036 m); 87 m (50 ms) thick in Andreasen L-32 (6560–6845 ft., 1999–2086 m); and 365 m (130 ms) thick in Satellite F-68 (8603–9800 ft., 2622–2987 m). Poor seismic resolution north of Satellite F-68 impedes a proper determination of the thickness of the formation on northernmost Prince Patrick Island. It is entirely possible that most, if not all, of the Trold Fiord sandstone gives way to van Hauen mudrock near Ballantyne Strait.

The sonic velocity of the van Hauen Formation ranges from 12 000 ft./s near the base to 18 000 ft./s near the top.

Lithology

Dark brownish grey to black, organic matter- and pyrite-rich, variably silty shale is the dominant lithology of the van Hauen Formation in the subsurface of Prince Patrick Island. Subordinate rock types include shaly siltstone, and variably argillaceous and silty limestone (Fig. 18). Chert, a dominant van Hauen lithology throughout the Sverdrup Basin, was not observed in the Prince Patrick wells.

The van Hauen succession is similar in both Jameson Bay C-31 and Andreasen L-32 where silty and sandy shale interfingers with shaly siltstone; some of the latter rock type is red, reflecting the oxidation of a pyrite-rich, micaceous matrix. The dark-coloured shales are very rich in pyrite as well as organic matter. Woody fragments are observed in some cuttings (Fig. 18a). Other minor lithologies include variably dolomitic, silty and argillaceous wackestones, packstone, and mixed clastic–carbonate rocks (Fig. 18b–d), with abundant bryozoans and brachiopods, and minor sponge spicules, echinoderms, ostracods, and small, agglutinated and frondicularid foraminifers.

A different succession occurs in Satellite F-68, where dark-coloured, organic matter- and pyrite-rich shale constitutes the dominant lithology. Minor siltstone and mixed clastic–carbonate rocks interfinger with the shale in the upper part of the formation. Such rocks occur in a 7 m core recovered from the upper part of the formation (8762–8740 ft., 2671–2664 m; Fig. 19a). The lower part of the core (8762.0–8758.5 ft., 2671–2670 m) is rich in pyrite, organic matter and minor phosphate, and comprises thoroughly bioturbated, dark grey to black, mixed silty shale–limestone with abundant bryozoans and brachiopods, and minor echinoderms and small, agglutinated foraminifers. Then follows a thin, unfossiliferous interval (8757.0–8758.5 ft., 2669–2670 m) characterized by faint parallel laminae and horizontal burrrows. The remainder of the core is composed of dark grey to black, brachiopod- and bryozoan-rich (ramose and fenestellid), mixed shaly siltstone–limestone (Fig. 19b). Other fossils include minor echinoderms and tiny foraminifers, arranged in alternating 5–15 cm thick, fossil-supported and matrix-supported couplets. The base of the fossil-supported horizons, which includes large brachiopods and bryozoans, is sometimes sharp and erosive, whereas its

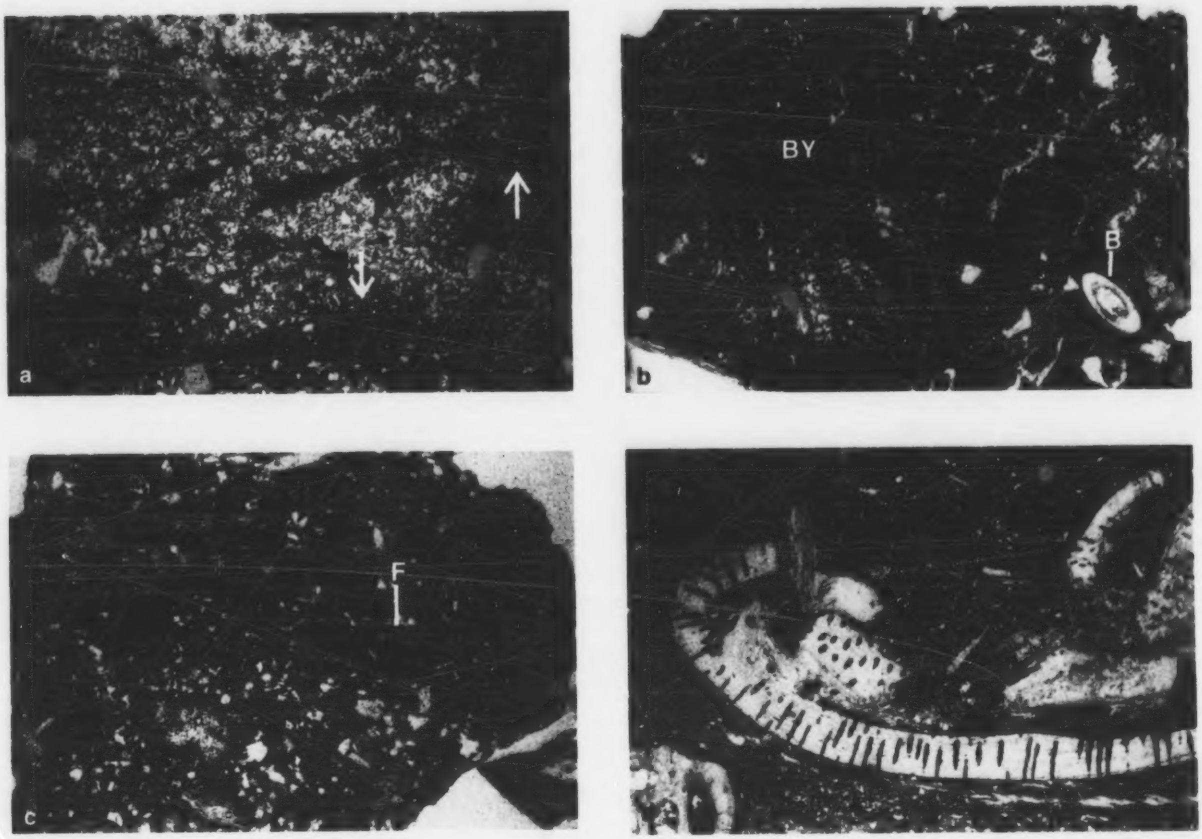

Figure 18. *Photomicrographs of well cuttings (**a-c**) and core (**d**) from van Hauen Formation.* ***a.*** *Shaly siltstone with abundant wood debris (arrows). Jameson Bay C-31, depth: 6250–6260 ft. (1905–1908 m); width of photograph: 3.30 mm; transmitted light.* ***b.*** *Argillaceous packstone with dolomitic matrix, bryozoans (BY) and brachiopod spines (B). Jameson Bay C-31, depth: 6250–6260 ft. (1905-1908 m); width of photograph: 3.30 mm; transmitted light.* ***c.*** *Mixed siltstone-limestone with uniserial foraminifer (F) within zoecia of fenestellid bryozoan. Andreasen L-32, depth: 6730–6750 ft. (2051–2057 m); width of photograph: 3.30 mm; transmitted light.* ***d.*** *Mixed silty shale-limestone with large punctate brachiopods. Black areas are pyrite and/or organic matter. Satellite F-68, depth: 8759.5 ft. (2670 m); width of photograph: 3.30 mm; transmitted light. (GSCC photos 4643-64, 63, 123, 44.)*

contact with the overlying matrix-supported rocks is gradational. In many cases, however, bioturbation has partly to completely destroyed these relationships. That part of the core also displays faint parallel laminae, and flame-like structures, which, along with the fining-upward packaging, suggest a turbiditic mode of transportation.

Seismic expression

The van Hauen Formation displays a series of laterally continuous reflectors that contrast with the more transparent nature of the underlying Trappers Cove and 'unnamed clastics' formations. Mudrocks of the van Hauen Formation cannot be readily differentiated seismically from sandstone of the Trold Fiord Formation (Fig. 8, 9), in spite of the obvious lithological difference.

Lower contact

The van Hauen Formation lies conformably on the Trappers Cove Formation in Satellite F-68, and unconformably on the Sabine Bay Formation in Jameson Bay C-31 and Andreasen L-32. The sub-van Hauen unconformity is angular and forms a sharp erosional surface that extends from south of Jameson Fault-B to the vicinity of Hemphill Fault-B.

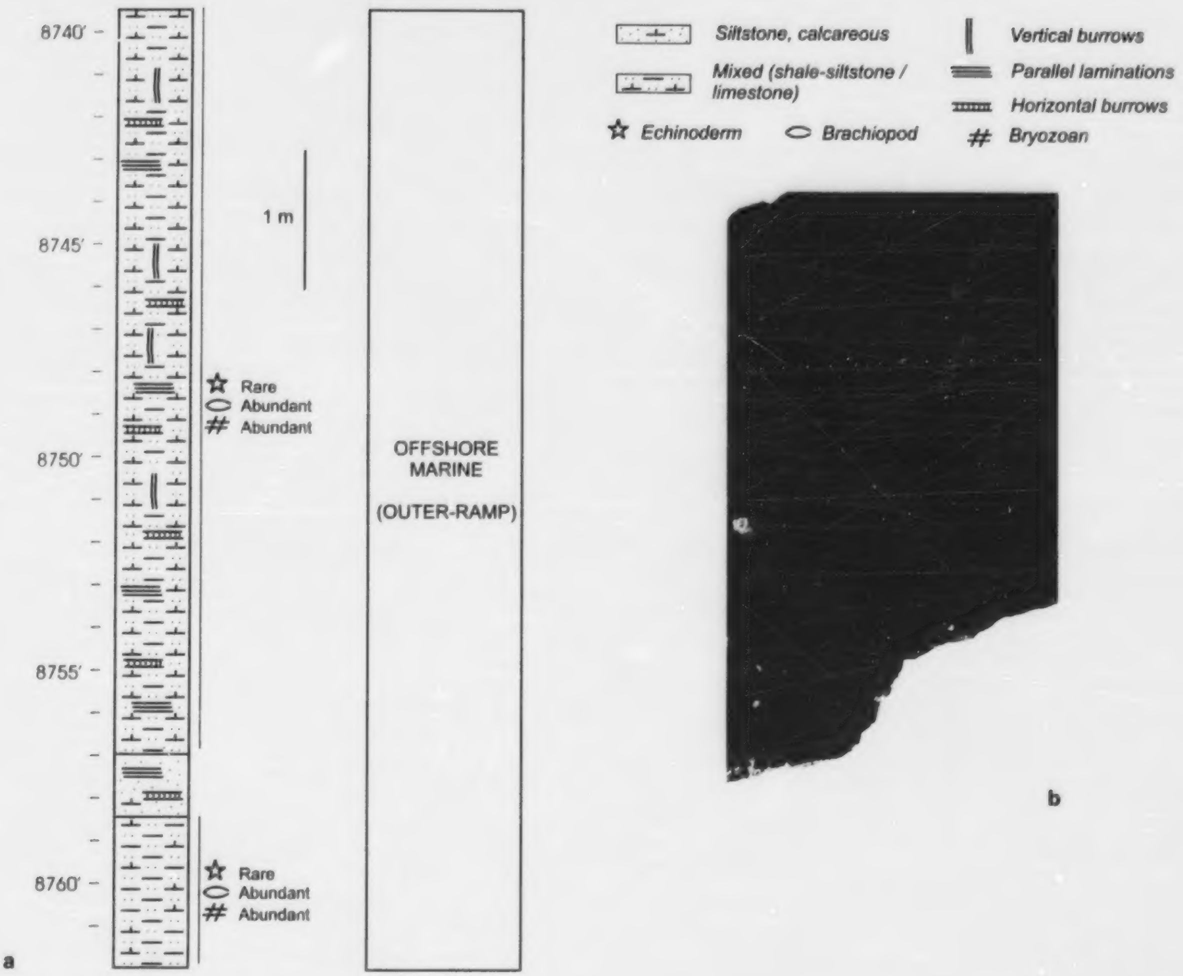

Figure 19. *Well core (8739–8762 ft.; 2664–2671 m) from van Hauen Formation in Satellite Bay F-68.* ***a.*** *Lithological log of core with depositional environment.* ***b.*** *Coarse-grained, brachiopod- and bryozoan-rich mixed shale-siltstone-limestone passing upward into fine-grained, fossil-poor, dark mudrock at 8755 ft. (2669 m). Scale bar is 5 cm. (GSCC photo 4643-13.)*

Age and correlation

Palynological assemblages belonging to the *Alisporites plicatus–Jugasporites compactus* Concurrent Range Zone of Roadian age and to the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age were recovered in three wells (Jameson Bay C-31, Andreasen L-32, Satellite F-68). Non-diagnostic Artinskian(?) or younger foraminifers were identified from Jameson Bay C-31 and Andreasen L-32 (Appendix 1).

Mudrock of the van Hauen Formation pass directly upward and cratonward into sandstone of the Trold Fiord Formation with no intervening carbonates (Degerböls Formation), as observed elsewhere in the Sverdrup Basin (Desrochers and Beauchamp, 1995). Shale and siltstone at the base of the van Hauen Formation may be correlative with the Kungurian as discussed under ‘Sequence stratigraphy’.

Depositional environment

The shale, siltstone, and minor limestone of the van Hauen Formation on Prince Patrick Island were deposited in deep-water, proximal (Jameson Bay C-31, Andreasen L-32) to distal (Satellite F-68) ramp, slope, and basinal fine-clastic environments, downslope from a sandstone-dominated ramp environment. In Jameson Bay C-31, the basal 30 m of the formation are transgressive, whereas the remainder is broadly regressive as it passes upward and laterally into sandstone of the Trold Fiord Formation. The proximal to distal northeastward transition was very gentle, as is evidenced by the lack of clinoforms on seismic profiles. Pelagic, hemipelagic, and turbiditic modes of sediment transport led to the accumulation of van Hauen sediments. Some of the limestone beds observed near the base of the formation in Jameson Bay C-31 and Andreasen L-32, and near the top of the formation in Satellite F-68 represent deep-water ramp benthic sedimentation in an environment that temporarily received little clastic sediment.

Trold Fiord Formation

Definition and type section

The Trold Fiord Formation is a Permian unit of green, glauconitic sandstone that lies at the margin of the Sverdrup Basin (Fig. 3), where it either rests unconformably on a number of older stratigraphic units, including Franklinian basement rocks, or conformably on sandstone of the Assistance Formation, carbonate of the Degerböls Formation, or as seen on Prince Patrick Island, mudrock of the van Hauen Formation. The Trold Fiord Formation is correlative with both the van Hauen and Degerböls formations. The type section is located on Hamilton Peninsula, west-central Ellesmere Island, where roughly 100 m of green, glauconitic, fossiliferous sandstone and minor chert pebble conglomerate and limestone were first described by Thorsteinsson (1974). In most areas, the Trold Fiord Formation comprises two units: a lower unit of fossiliferous sandstone and minor limestone; and an upper unit of mostly unfossiliferous sandstone with minor sponge spicules and phosphatic brachiopods. In some areas, this upper sandstone unit interfingers with a variably sandy spiculitic chert.

Distribution, thickness, and sonic velocity

The Trold Fiord Formation is the most widespread upper Paleozoic unit in the subsurface of Prince Patrick Island, where it thickens from zero to probably more than 1 km in a northeasterly direction (Fig. 6–9). The thickness of the drilled formation is 24 m (50 ms) at Intrepid Inlet H-49 (4140–4220 ft., 1262–1286 m), 250 m (125 ms) at Jameson Bay C-31 (5350–6172 ft., 1631–1881), 332 m (170 ms) at Andreasen L-32 (5470–6560 ft., 1667–1999 m), and 763 m (300 ms) at Satellite F-68 (6100–8603 ft., 1859–2622 m). The Trold Fiord succession in Satellite F-68 is the thickest ever measured in a well or a surface section anywhere in the Sverdrup Basin.

The sonic velocity of the Trold Fiord Formation clusters between 11 000 and 13 000 ft./s at Intrepid Inlet H-49, between 12 000 and 14 000 ft./s at Jameson Bay C-231 and Andreasen L-32, and between 14 000 and 20 000 ft./s at Satellite F-68.

Lithology

Greenish grey, variably calcareous and glauconitic, fine- to medium-grained sandstone constitutes the dominant Trold Fiord lithology (Fig. 20). Clastic detritus consists of quartz (60 to 95%), chert (15 to 40%), glauconite (0 to 10%), and pyrite, bitumen, and woody debris (up to 10%). Rare fossils include sponge spicules and phosphatized brachiopods. Glauconitic and phosphatic shaly matrix as well as calcareous and silica cements occlude the interparticle porosity. These sands were thoroughly bioturbated, and various burrow types filled with finer grained, commonly phosphatic- and organic-matter-rich material, are numerous.

Subordinate Trold Fiord lithologies include: 1) faintly laminated, silty to sandy, calcareous, spiculitic chert, with rare bryozoans and brachiopods; 2) mixed clastic–carbonate with abundant bryozoans and brachiopods, and minor frondicularid foraminifers; 3) greenish red silty shale and siltstone; 4) light- to medium-grey siltstone and shale; 5) chert pebble conglomerate and pebbly sandstone; and 6) black, organic-rich, coaly shale. The latter lithology comprises liptinite-rich, coal-like shales that occur as thin (< 1 m) units at Intrepid Inlet H-49 (4226 ft., 1288 m), Andreasen L-32 (6022 ft., 1836 m and 6245 ft., 1903 m) and Satellite F-68 (6990 ft., 2131 m). These horizons are difficult to see in Figures 6 and 7.

A 3 m long core was recovered from the Trold Fiord Formation in Satellite F-68 (7120–7131 ft., 2170–2173 m; Fig. 21a). The core comprises pale greenish grey, fine grained, slightly glauconitic (grains and matrix) sandstone, displaying contorted, organic-matter-rich black stringers, and locally preserved parallel laminae in an otherwise thoroughly bioturbated fabric (Fig. 21b, c). The terrigenous fraction comprises up to 30 per cent chert grains. Yellowish brown siltier pods, 1–3 cm in size, occur throughout; they are probably a result of bioturbation. Some vertical burrows were observed locally. A thin, sharp-based, dark grey to black, organic-matter- and pyrite-rich stylolitized interval (7126–7127 ft., 2172–2172.3 m) interrupts the otherwise monotonous sandstone succession.

Seismic expression

The Trold Fiord Formation displays in its upper part a series of laterally continuous parallel reflectors that can be readily traced over long distances. The bulk of the formation is more transparent, that is, with fewer well-defined reflectors, allowing it to be differentiated from the more reflective van Hauen Formation.

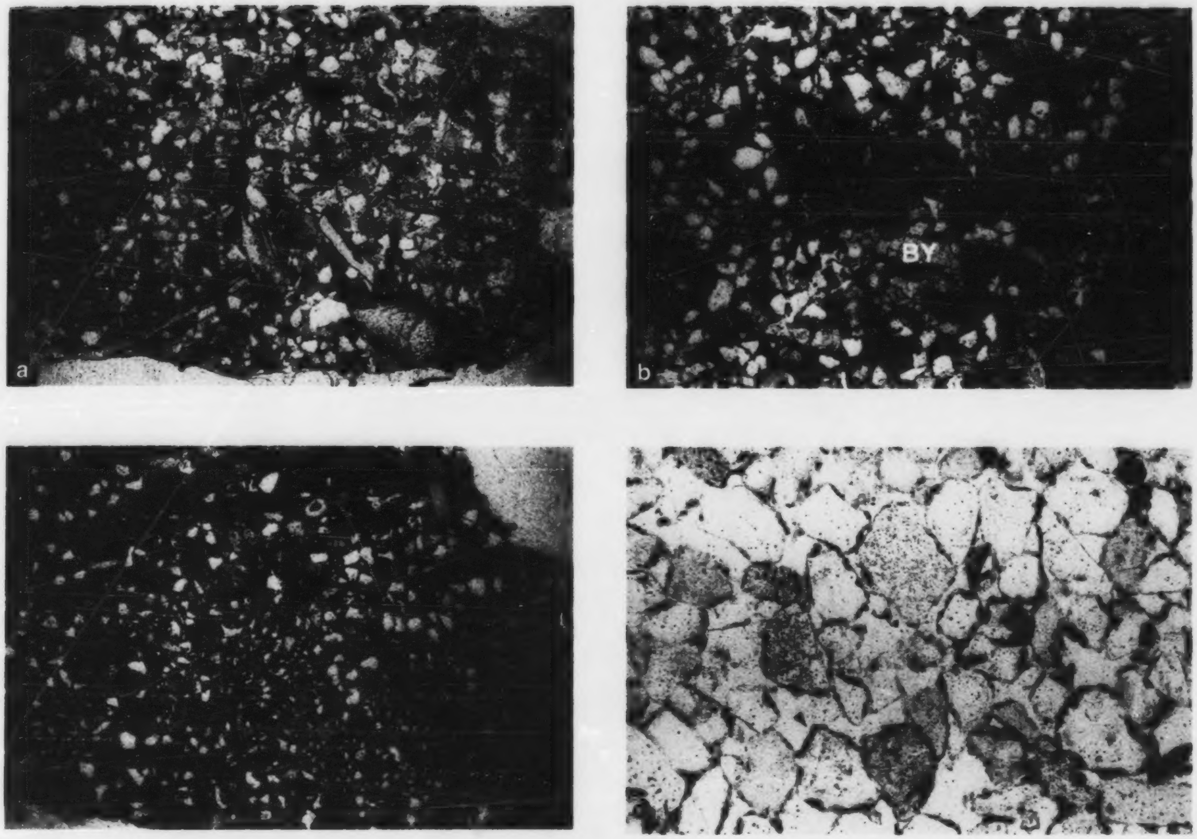

Figure 20. *Photomicrographs of well cuttings (**a-c**) and core (**d**) from Trold Fiord Formation.* ***a.*** *Fine-grained calcareous, glauconitic sandstone with abundant phosphatic brachiopod debris. Grey grains are glauconite. Jameson Bay C-31, depth: 5430–5450 ft.(1655–1661 m); width of photograph: 3.30 mm, transmitted light.* ***b.*** *Calcareous, fine-grained sandstone with bryozoan debris (BY). Dark areas are pyrite and/or organic matter. Andreasen L-32, depth: 6000–6010 ft. (1829–1832 m); width of photograph: 3.30 mm, transmitted light.* ***c.*** *Calcareous, silty and shaly, fine-grained sandstone with abundant sponge spicules. Satellite F-68, depth: 6350–6360 ft. (1935–1939 m); width of photograph: 3.30 mm, transmitted light.* ***d.*** *Fine-grained sandstone. Quartz (clear) and chert (pitted) grains are rimmed by thin glauconite rind (arrows) and tightly cemented by a later quartz phase. Satellite F-68, depth: 7130 ft. (2173 m); width of photograph: 1.25 mm, transmitted light. (GSCC photos 4643-57, 117, 93, 37.)*

Lower contact

A gradational contact between the Trold Fiord Formation and the underlying van Hauen Formation was observed in Jameson C-31, Andreasen L-32, and Satellite F-68 (Fig. 6, 7). The Trold Fiord Formation rests unconformably on the Franklinian basement (Beverly Inlet Formation) in Intrepid Inlet H-49 (Fig. 7, 9). An intraformational unconformity occurs at 4260 ft. (1298 m) in that well, where chert pebble conglomerate lies sharply on shale and siltstone contained in the lower part of the formation.

Age and correlation

The presence of the foraminifer "*Frondicularia*" *ganelinae* from the 6350–6360 ft. (1935–1938 m) interval in Satellite F-68 suggests a Guadalupian to Lopingian age for the Trold Fiord Formation. Long-ranging indeterminate "frondicularid" and geinitzinid" foraminifers in other wells suggests an Artinskian or younger age (Appendix 1).

Abundant palynological taxa belonging to the *Ahrensisporites thorsteinssonii–Scutasporites nanuki*

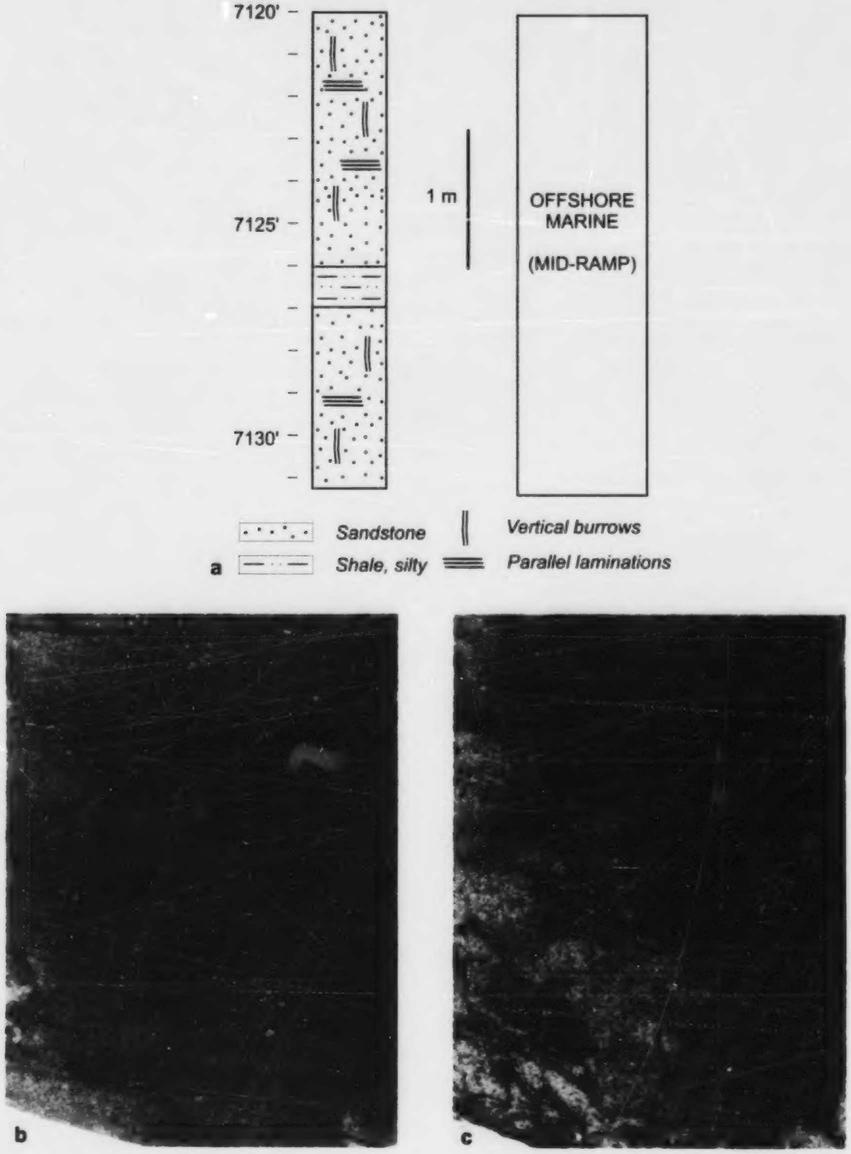

Figure 21. *Well core (7120–7131 ft.; 2170–2174 m) from Trold Fiord Formation in Satellite Bay F-68.* ***a.*** *Lithological log of core with depositional environment.* ***b.*** *Fine-grained sandstone with faint parallel laminae at 7121 ft. (2170 m). Scale bar is 5 cm.* ***c.*** *Bioturbated fine-grained sandstone with vertical burrows at 7130 ft. (2173 m). Scale bar is 5 cm.*

Concurrent Range Zone of Utting (1994) were recovered at different stratigraphic levels in all four wells under study (Fig. 8, 9; Appendix 1). This zone is correlated with the Wordian Stage by Utting (1994), who evoked the possibility that some of the strata that yield this palynoflora in the Sverdrup Basin may extend higher into the Guadalupian (Capitanian). Accordingly, the conodont *Mesogondella phosphoriensis*, indicative of a Wordian age (zone P13 of Beauchamp et al., 1989a), and an assemblage comprising *M. rosenkrantzi* and *M. bitteri* (zone P14 of Beauchamp et al., 1989a), now believed to be indicative of a Capitanian age (C.M. Henderson, pers. comm., 1999), are known to coexist with palynoflora representative of the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Zone on Grinnell Peninsula, Devon Island (Beauchamp et al., 1998), and Hamilton Peninsula, west-central Ellesmere Island (Utting, 1994; Henderson, 1981).

At Hamilton Peninsula, *M. rosenkrantzi* and *M. bitteri* have been documented from within the upper part of the Trold Fiord Formation some 25 m below the contact with the Triassic Bjorne Formation and about 30 m above a prominent chert pebble conglomeratic unit (Henderson, 1981). This conglomerate is closely associated with a major unconformity within the Trold Fiord Formation, one that marks a significant sequence boundary within both the Trold Fiord and correlative Degeböls formations throughout the Sverdrup Basin. This includes Prince Patrick Island, where an unconformity associated with chert pebble conglomerate occurs at 4260 ft. (1298 m) at Intrepid Inlet H-49 and 5920 ft. (1804 m) at Jameson Bay C-31 (Fig. 6, 22). A correlative unconformity without associated chert pebbles occur at 6130 ft. (1868 m) at Andreasen L-32 and 7310 ft. (2228 m) at Satellite F-68 (Fig. 7, 23). Based on comparisons with other areas and providing that the Capitanian age assignment for the *M. rosenkrantzi* and *M. bitteri* assemblage is correct, it is believed that the upper part of the Trold Fiord Formation on Prince Patrick Island, that is, the succession above the intraformational unconformity, is mostly Capitanian in age. The sequence stratigraphic significance of this unconformity will be discussed under 'Sequence stratigraphy'.

Depositional environment

The depositional environments of Trold Fiord sediments ranged from nonmarine coastal deposits in Intrepid Inlet H-49 to relatively deep-water, open-marine clastic ramp deposits in the other three wells. On Prince Patrick Island, the Trold Fiord Formation passes basinward into van Hauen siltstone and shale, which were deposited in distal, deep-water ramp, slope to basinal environments.

SEQUENCE STRATIGRAPHY

The upper Paleozoic succession of Prince Patrick Island contains eight major unconformities that can be correlated over a significant area. Five of these unconformities were encountered in Jameson Bay C-31, Intrepid Inlet H-49, and Andreasen L-32 (Fig. 22, 23). Three additional unconformities were observed on seismic profiles only (Fig. 24, 25). The eight unconformities and the seven sequences between them have been traced seismically using a series of profiles shown in Figures 24 to 30. An isopach map for each sequence is depicted in Figures 31 to 37.

Serpukhovian(?) Sequence

The Serpukhovian(?) sequence has a limited geographic distribution on northern Prince Patrick Island, where it forms two tapering wedges that abut against Hemphill Fault-A and Moore Bay Fault-A (Fig. 31). The two wedges are separated by an area of nondeposition and/or erosion. The sequence comprises up to 500 ms (Fig. 31) or about 1 km of assumed clastic rocks, the bulk of which is believed to belong to the Borup Fiord Formation.

Lower sequence boundary

The lower sequence boundary of the Serpukhovian(?) Sequence is the angular unconformity that separates the Borup Fiord(?) Formation and the Franklinian basement between Hemphill Fault-A and Moore Bay Fault-A (Fig. 24, 25, 30).

Upper sequence boundary

The upper sequence boundary is the seismic surface that separates inclined reflectors assigned to the Borup Fiord Formation and subhorizontal reflectors of the overlying Nansen Formation, between Hemphill Fault-A and Moore Bay Fault-A (Fig. 24, 25). This surface is interpreted as an angular unconformity.

Transgressive systems tract

The Serpukhovian Sequence is assumed to be represented by increasingly marine, syn-rift, half-graben clastic fills (sandstones and conglomerates), the bulk of which was deposited in a series of alluvial fans and braided rivers. The inclined reflectors are indicative of extension and block rotation in opposite facing directions, while the area of nondeposition/erosion between the two half grabens probably represents a syn-rift uplift or accommodation zone.

In the Sverdrup Basin, the transgressive systems tract of the Serpukhovian Sequence is represented by the Borup Fiord Formation, a fluvial to marginal-marine succession that appears to be restricted to half-graben structures and attains nearly 1 km in thickness locally. This succession is overlain by a relatively thin (less than 100 m) marine to nonmarine regressive succession of carbonates and sandstones of Early Bashkirian age that lies at the base of the Nansen and Canyon Fiord formations and extends much beyond the Borup Fiord-bearing half-graben structures. Limited seismic evidence suggests that only the transgressive systems tract of the Serpukhovian Sequence occurs in the subsurface of Prince Patrick Island.

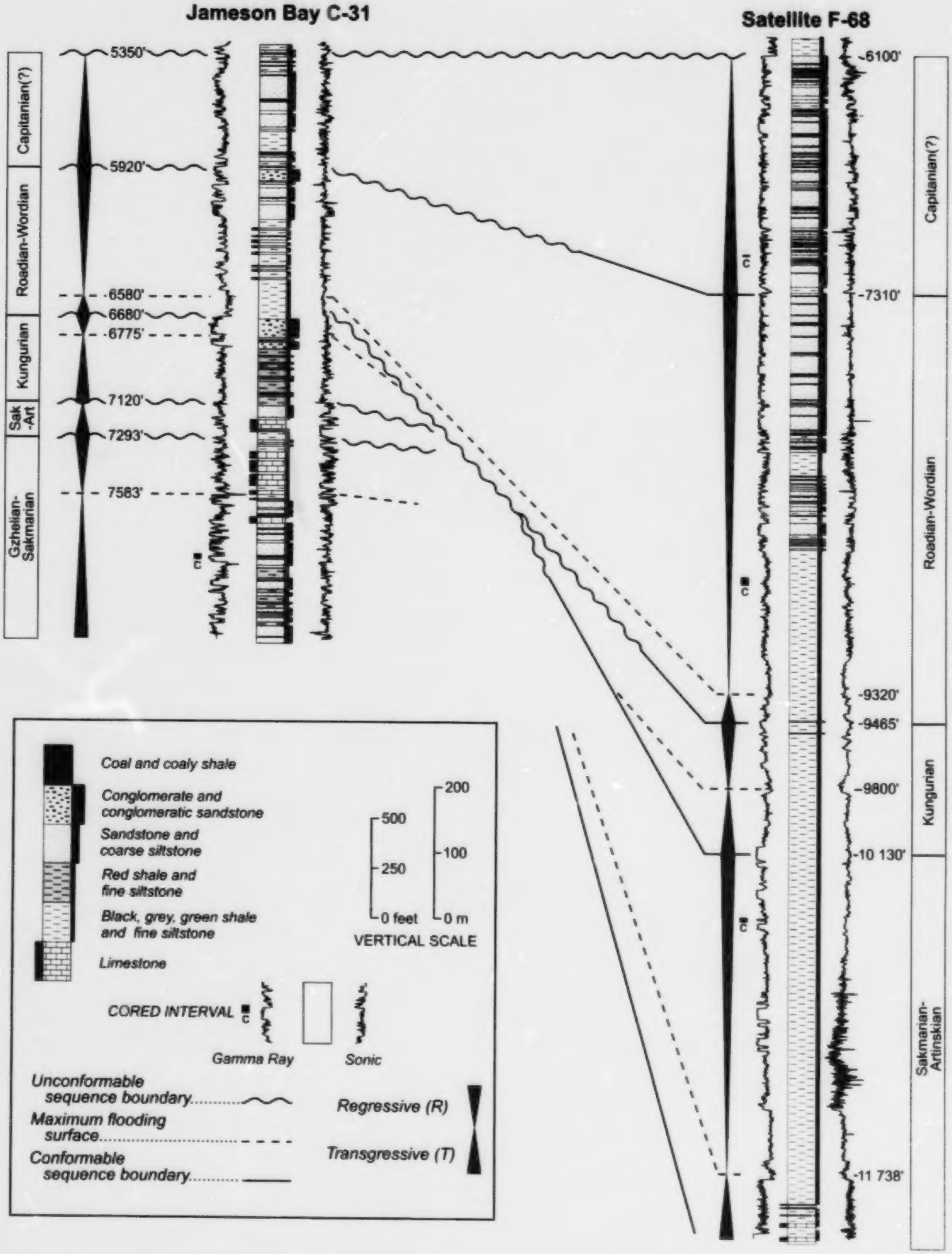

Figure 22. *Sequence stratigraphic cross-section between Jameson Bay C-31 and Satellite F-68 showing gamma ray and sonic logs, lithologies, stratigraphic position (in ft.) of major unconformable and conformable sequence boundaries and maximum flooding surfaces, long-term transgressive and regressive trends, sequence ages and correlations.*

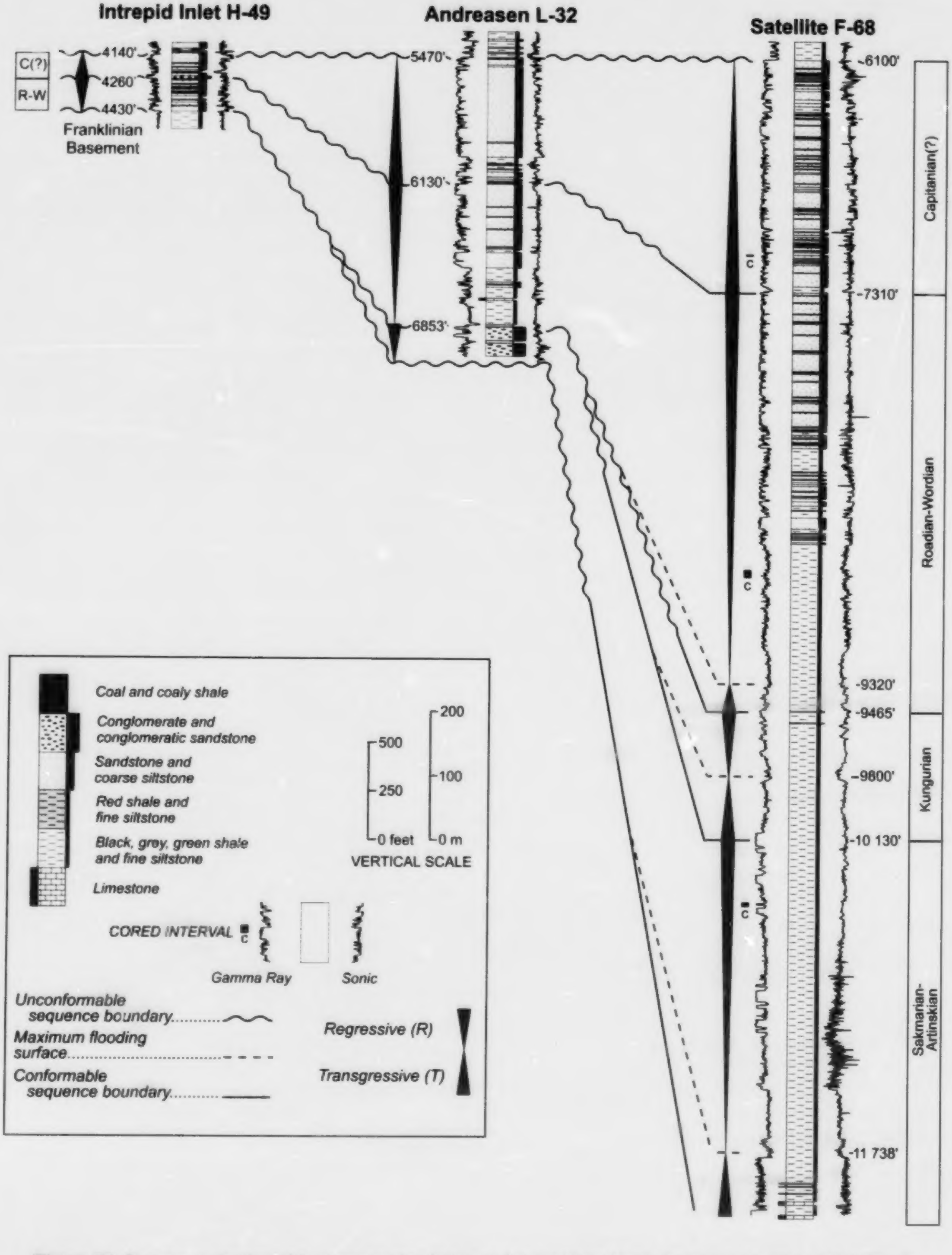

Figure 23. *Sequence stratigraphic cross-section between Intrepid Inlet H-49, Andreasen L-32 and Satellite F-68 showing gamma ray and sonic logs, lithologies, stratigraphic position (in ft.) of major unconformable and conformable sequence boundaries and maximum flooding surfaces, long-term transgressive and regressive trends, sequence ages and correlations.*

Bashkirian–Kasimovian Sequence

The Bashkirian–Kasimovian Sequence has a wide geographic distribution throughout Prince Patrick Island (Fig. 32). The sequence is represented by up to 560 ms (about 1.5 km) of clastics, carbonates and mudrocks assigned to the Canyon Fiord, Nansen, and Hare Fiord formations (Fig. 22–30). Two prominent depositional trends are obvious from the isopach map (Fig. 32): 1) a northwest–southeast trend in the northern areas, where the sequence forms a broad wedge that thickens from zero to more than 480 ms over a distance of about 20 km and then thins again in a northeasterly direction (Fig. 29, 30); and 2) a northeast–southwest trend in the southern areas, where two relatively narrow depocentres, each more than 500 ms thick, are separated by an elongated basement high upon which the sequence is locally as thin as 80 ms (Fig. 27, 28).

The thickness of the Bashkirian–Kasimovian Sequence also varies slightly across the nine, named, northwest–southeast faults shown in Figure 32. As discussed under the next heading, extension and block rotation occurred along those faults during deposition of the younger Gzhelian–Sakmarian Sequence. It is likely that thickness variations across these faults mostly reflect post-Kasimovian erosion resulting from Gzhelian and Asselian footwall uplift (Fig. 24). One cannot, however, completely rule out the possibility that the northwest–southeast faults were active during the Bashkirian–Kasimovian interval, as will be discussed below under 'Regional and economic implications'.

This sequence is assigned to the Bashkirian–Kasimovian time interval because it lies beneath dated Gzhelian or Asselian Canyon Fiord strata in Jameson Bay C-31 and above assumed Serpukhovian Borup Fiord strata between Hemphill Fault-A and Moore Bay Fault-A. An equivalent sequence contains Bashkirian to Kasimovian fossils throughout Ellesmere Island (Beauchamp et al., 1995a; Henderson et al., 1995; Rui et al., 1991).

Lower sequence boundary

Throughout most of the study area, the lower sequence boundary of the Bashkirian-Kasimovian Sequence is the angular unconformity that separates the upper Paleozoic succession from the underlying Franklinian basement (Fig. 24–30). The unconformity lies between strata assigned to the Borup Fiord and Nansen formations between Hemphill Fault-A and Moore Bay Fault-A (Fig. 24, 25, 30), as discussed under the previous heading.

Upper sequence boundary

The upper sequence boundary is an unconformity evidenced by the updip truncation (toplap surface) of seismic reflectors, such as shown north of Jameson Fault-A (Fig. 24), south of Hemphill Fault-B (Fig. 24), west of Jameson Fault-A (Fig. 26), west and east of John Point Fault (Fig. 27), and west of Hemphill Fault-C (Fig. 28, 29).

Maximum flooding surface

The maximum flooding surface is questionably assigned in Figures 27, 28 and 29 to a seismic horizon that lies between a lower, transparent, reflector-free succession and an upper succession of better defined, laterally continuous reflectors. Based on knowledge derived from outcrops on Devon and Ellesmere islands (Beauchamp et al., 1998; Beauchamp and Thériault, 1994; Thériault 1991; Thériault and Beauchamp, 1991), it is speculated that the lower, transparent succession is dominated by a homogenous suite of sandstone and conglomerate of the Lower clastic member of Canyon Fiord Formation, whereas the upper, reflective succession is represented by typical, carbonate-dominated shelf cycles of the Middle limestone member of the Canyon Fiord Formation. In general, the maximum flooding surface lies near the transition between the two members (Beauchamp, 1987; Riediger and Harrison, 1993).

Transgressive systems tract

The seismically transparent lower portion of the Bashkirian–Kasimovian Sequence is believed to be equivalent to the Lower clastic member of the Canyon Fiord Formation. Its very irregular distribution in Figures 27 and 28 is suggestive of deposition within two relatively narrow depressions bounded by basement highs, as also shown in the isopach map (Fig. 32). Poorly defined reflectors within the succession appear to diverge and onlap a basement high in a generally easterly direction in both Figures 27 and 28. We surmise that these two depressions were tectonically active during deposition of the assumed Bashkirian–early Moscovian transgressive systems tract and that they formed half-grabens bounded by two, low-angle northeast-trending faults, hereafter referred to as NE Prince Patrick Fault-A and -B (Fig. 27, 28). With this interpretation, the elongated northeast-southwest trending basement high shown in Figure 32 represents the footwall uplift associated with NE Prince Patrick Fault-A. A similar high probably lies immediately east of NE Prince Patrick Fault-B, beyond the reach of seismic line 467.

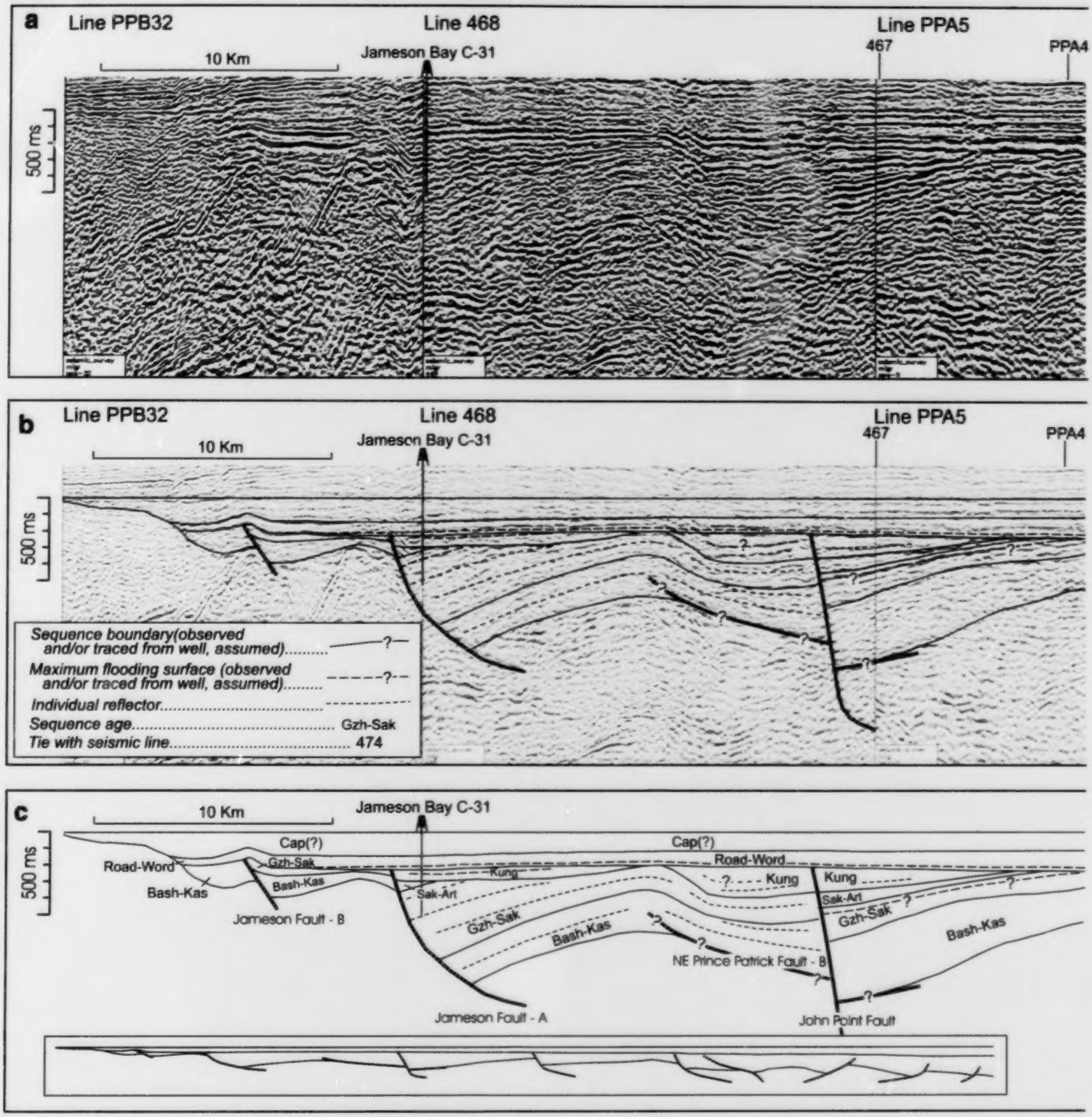

***Figure 24.** Composite seismic profile C31F68, flattened to base Triassic. **a.** Uninterpreted profile. **b.** Sequence statigraphic interpretation. **c.** Sequence statigraphic interpretation with annotations. Inset depicts sub-Triassic, mid-Permian and sub-Carboniferous sequence boundaries at 1:1 scale.*

Throughout the Sverdrup Basin, the transgressive systems tract of the Bashkirian–Kasimovian Sequence comprises Bashkirian to Early Moscovian, red, alluvial fan and fluvial conglomerate and sandstone that pass upward into increasingly marine sandstone and carbonate. The bulk of this succession was deposited contemporaneously with a phase of crustal extension and block rotation at the margin of the Sverdrup Basin. These rocks constitute the Lower clastic member of the Canyon Fiord Formation, which forms a crudely bedded, massive-looking unit that contrasts sharply with the better-stratified carbonate shelf cycles above (Middle limestone member).

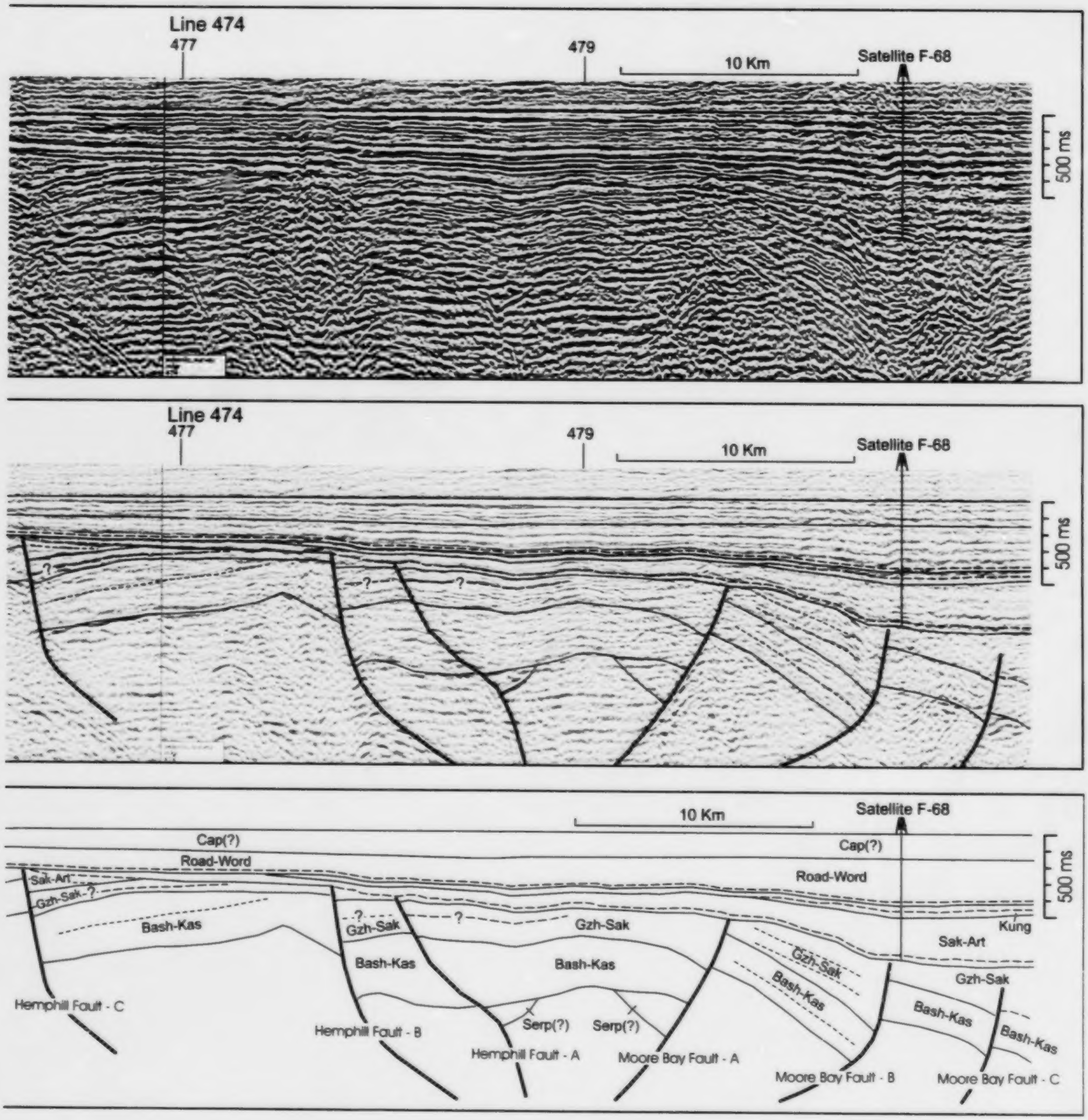

Figure 24. *Composite seismic profile C31F68 continued.*

Regressive systems tract

On Prince Patrick Island, the regressive systems tract of the Bashkirian–Kasimovian Sequence is assumed to correspond to the series of laterally continuous reflectors that occur above the seismically transparent succession interpreted as the transgressive systems tract. The laterally continuous reflectors are likely to represent carbonate-dominated shelf strata belonging to the Middle limestone member of the Canyon Fiord formation and, in the more distal area, to the

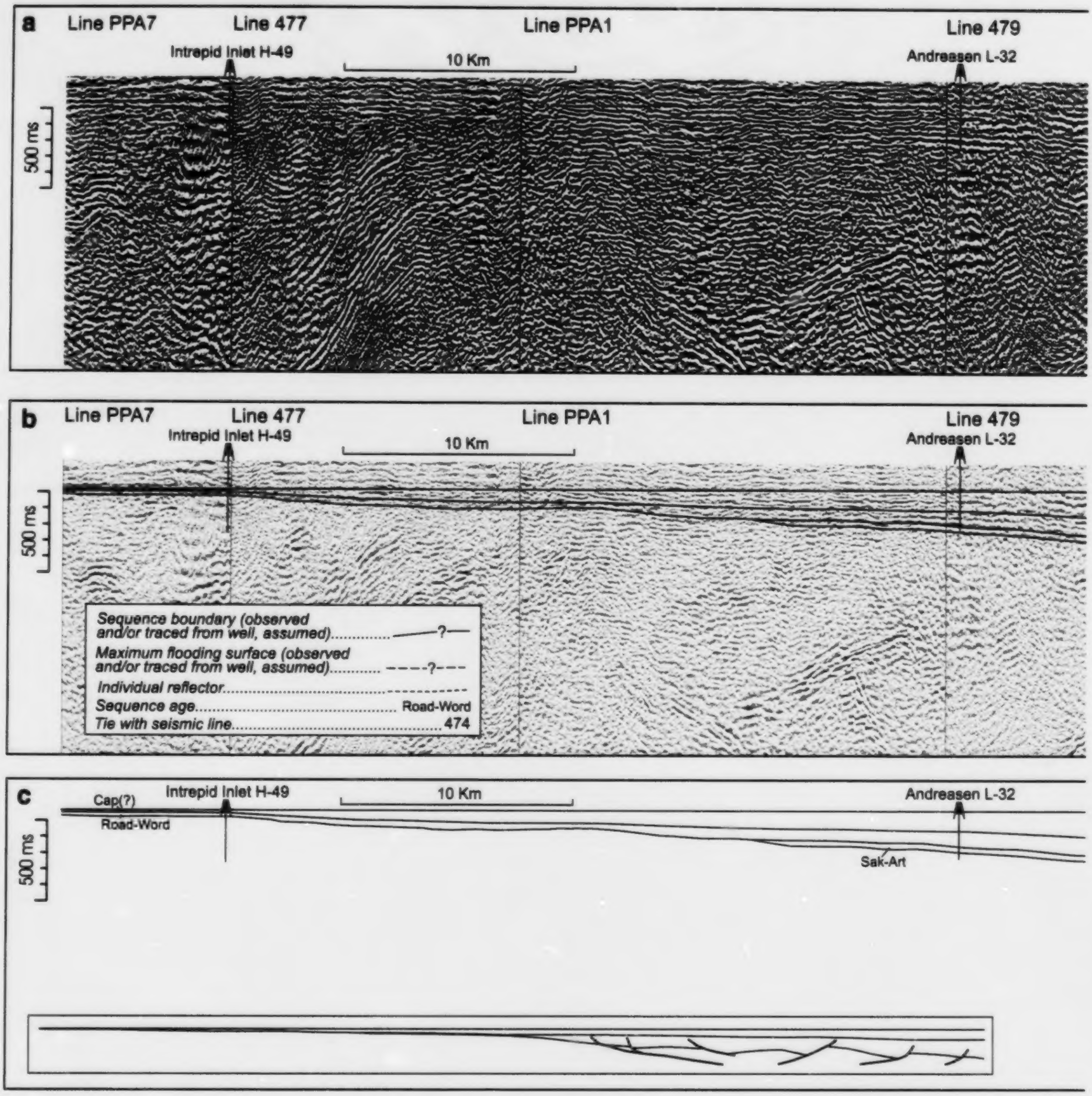

Figure 25. *Composite seismic profile H49L32F68, flattened to base Triassic.* ***a.*** *Uninterpreted profile.* ***b.*** *Sequence statigraphic interpretation.* ***c.*** *Annotations. See Figure 2 for location. Inset in* ***c*** *depicts sub-Triassic, mid-Permian and sub-Carboniferous sequence boundaries at 1:1 scale.*

Nansen Formation. This succession passes basinward into mudrock of the Hare Fiord Formation. Convex-up reflectors between Hemphill Fault-A and Moore Bay Fault-A (Fig. 24, 25) evoke the shape of carbonate buildups, but these features could equally represent some geophysical artefacts.

In the northern areas of Prince Patrick Island, it is likely that the Moscovian to Kasimovian shelf-to-basin transition, roughly expressed as the lateral contact between the Nansen and Hare Fiord formations, takes place somewhere between Hemphill Fault-A and Moore Fault-B, where the succession

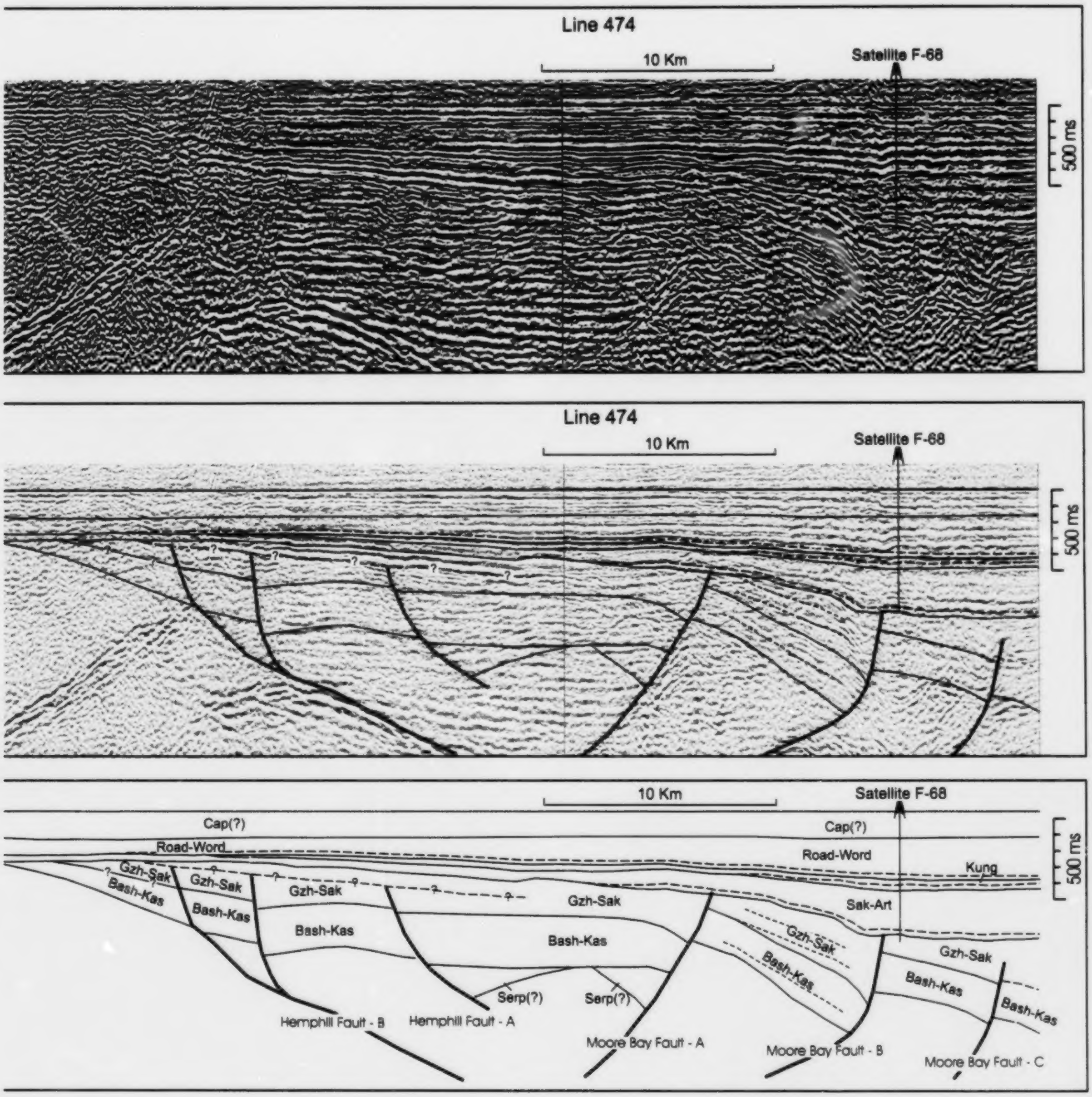

Figure 25. *Composite seismic profile H49L32F68 continued.*

attains its maximum thickness (Fig. 32). In the southern areas (Fig. 27), the regressive systems tract thickens to the east and northeast. The succession seems to postdate faulting along NE Prince Patrick Fault-A, and likely along NE Prince Patrick Fault-B as well. It thus appears that the bulk, if not all, of the Moscovian to Kasimovian regressive systems tract prograded basinward during a phase of passive subsidence that followed crustal extension and deposition of the Bashkirian–Early Moscovian syntectonic transgressive systems tract.

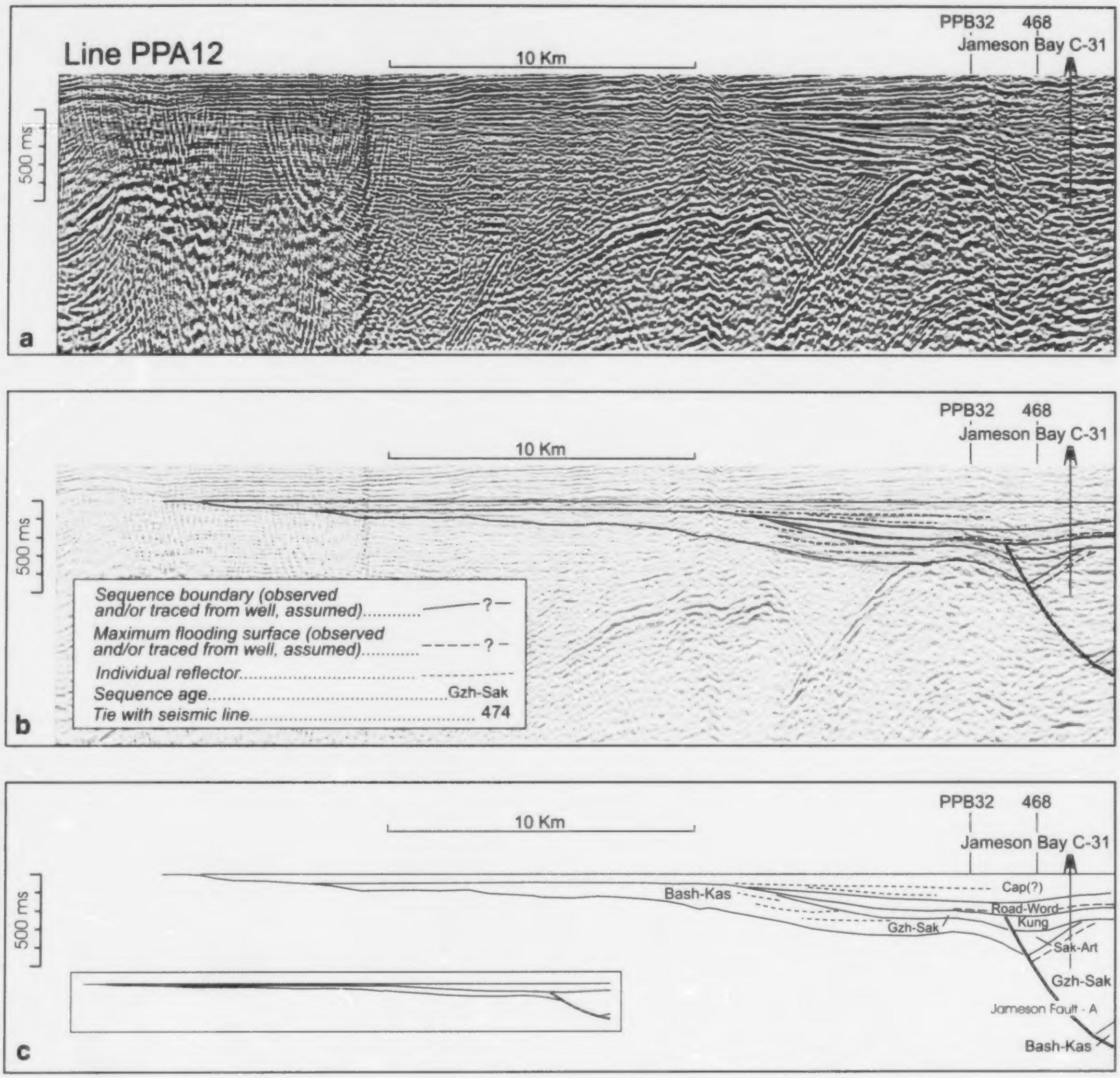
Line PPA12
PPB32
468
Jameson Bay C-31
10 Km
500 ms
a
b
Sequence boundary (observed and/or traced from well, assumed)............ ?
Maximum flooding surface (observed and/or traced from well, assumed)............ ?
Individual reflector....................................
Sequence age....................................Gzh-Sak
Tie with seismic line....................................474
c
Cap(?)
Bash-Kas
Road-Word
Kung
Gzh-Sak
Sak-Art
Gzh-Sak
Jameson Fault - A
Bash-Kas

Figure 26. *Seismic profile PPA12, flattened to base Triassic.* ***a.*** *Uninterpreted.* ***b.*** *Sequence stratigraphic interpretation.* ***c.*** *Annotations. See Figure 2 for location. Inset in* ***c*** *depicts sub-Triassic, mid-Permian and sub-Carboniferous sequence boundaries at 1:1 scale.*

Throughout the Sverdrup Basin, Moscovian to Kasimovian strata form a very thick, regressive and progradational succession of cyclic shelf carbonates and mixed clastic-carbonates (Middle limestone member of Canyon Fiord Formation, Nansen and Antoinette formations) that pass basinward into slope-to-basinal mudrock (Hare Fiord Formation). The shelf-edge is in many areas marked by the presence of large carbonate buildups, many of which attain thicknesses exceeding 500 m, such as on Hvitland Peninsula, northwest Ellesmere Island (Beauchamp et al., 1995c).

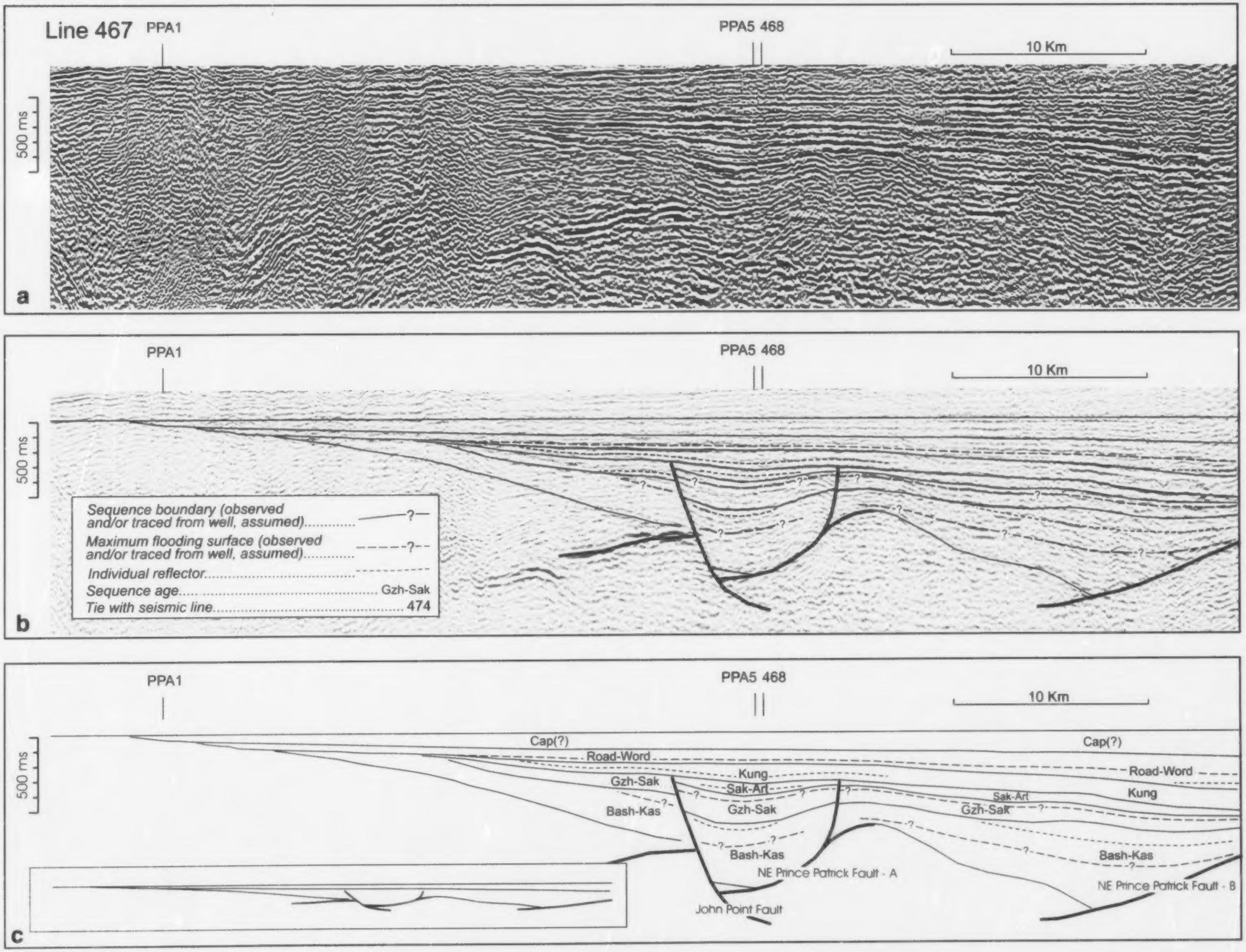
Line 467
PPA1
PPA5 468
10 Km
500 ms
a
b
Sequence boundary (observed and/or traced from well, assumed)............ ?
Maximum flooding surface (observed and/or traced from well, assumed)............ ?
Individual reflector.................................
Sequence age.. Gzh-Sak
Tie with seismic line.. 474
c
Cap(?)
Road-Word
Kung
Sak-Art
Gzh-Sak
Bash-Kas
NE Prince Patrick Fault - A
NE Prince Patrick Fault - B
John Point Fault

Figure 27. Seismic profile 467, flattened to base Triassic. **a.** Uninterpreted. **b.** Sequence stratigraphic interpretation. **c.** Annotations. See Figure 2 for location. Inset in **c** depicts sub-Triassic, mid-Permian and sub-Carboniferous sequence boundaries at 1:1 scale.

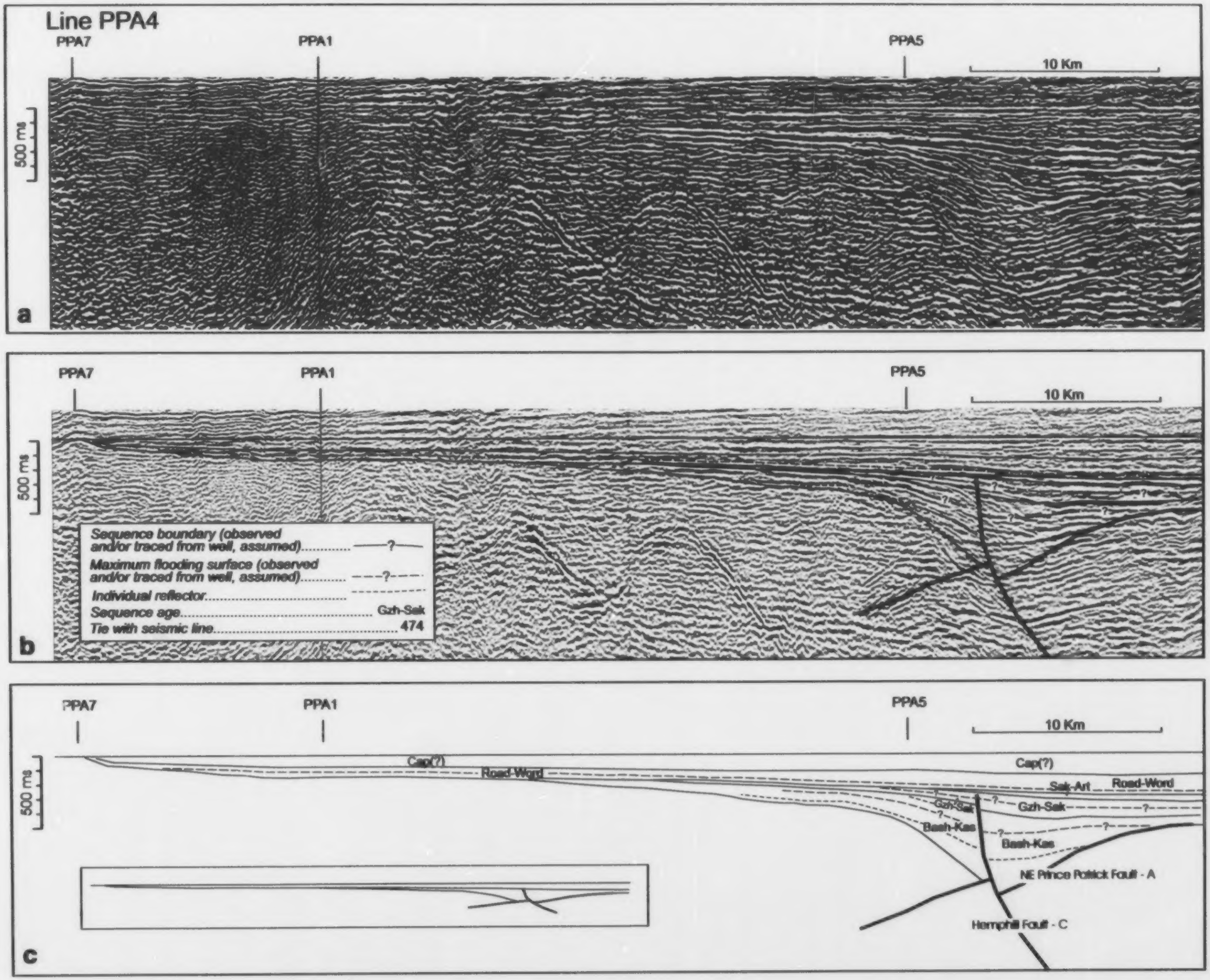

Figure 28. Seismic profile PPA4, flattened to base Triassic. **a.** Uninterpreted. **b.** Sequence stratigraphic interpretation. **c.** Annotations. See Figure 2 for location. Inset in **c** depicts sub-Triassic, mid-Permian and sub-Carboniferous sequence boundaries at 1:1 scale.

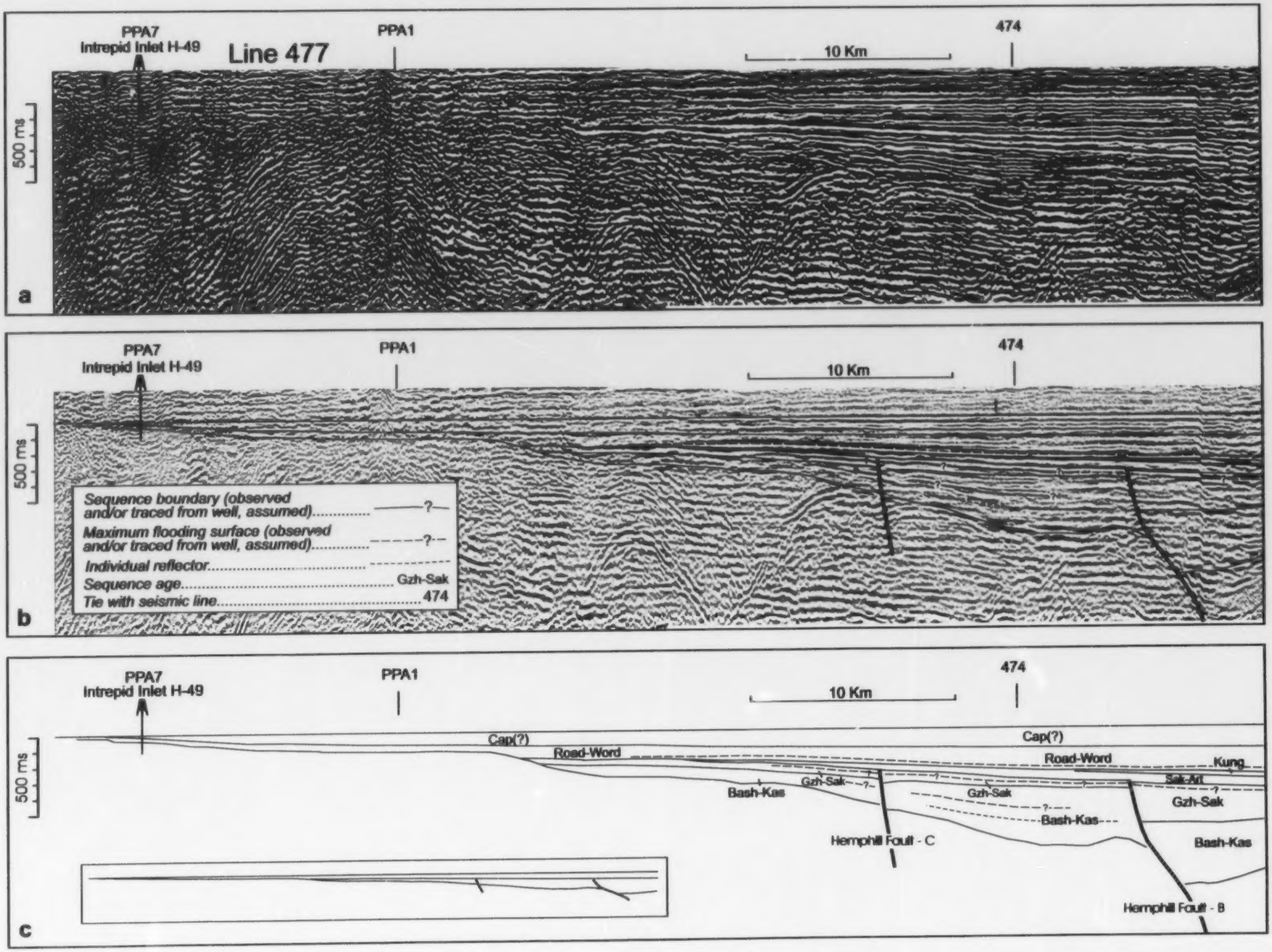

Figure 29. Seismic profile 477, flattened to base Triassic. **a.** Uninterpreted. **b.** Sequence stratigraphic interpretation. **c.** Annotations. See Figure 2 for location. Inset in **c** depicts sub-Triassic, mid-Permian and sub-Carboniferous sequence boundaries at 1:1 scale.

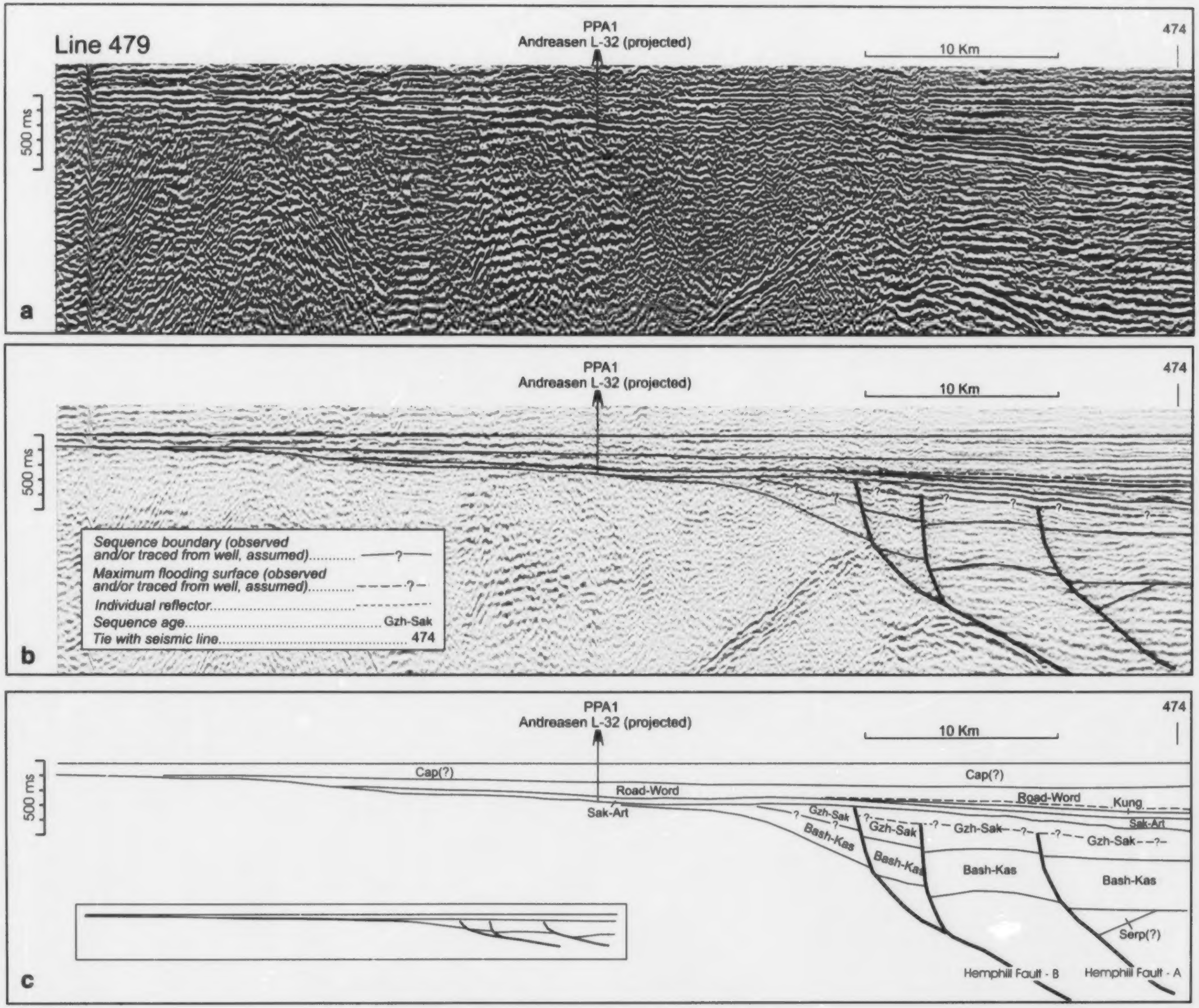

Figure 30. *Seismic profile 479, flattened to base Triassic.* ***a.*** *Uninterpreted.* ***b.*** *Sequence stratigraphic interpretation.* ***c.*** *Annotations. See Figure 2 for location. Inset in* ***c*** *depicts sub-Triassic, mid-Permian and sub-Carboniferous sequence boundaries at 1:1 scale.*

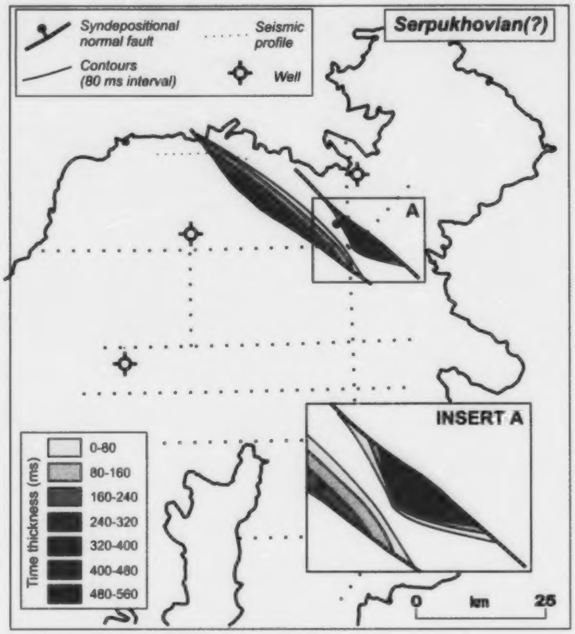

Figure 31. Isopach map of Serpukhovian(?) Sequence. Time thickness is in milliseconds (ms).

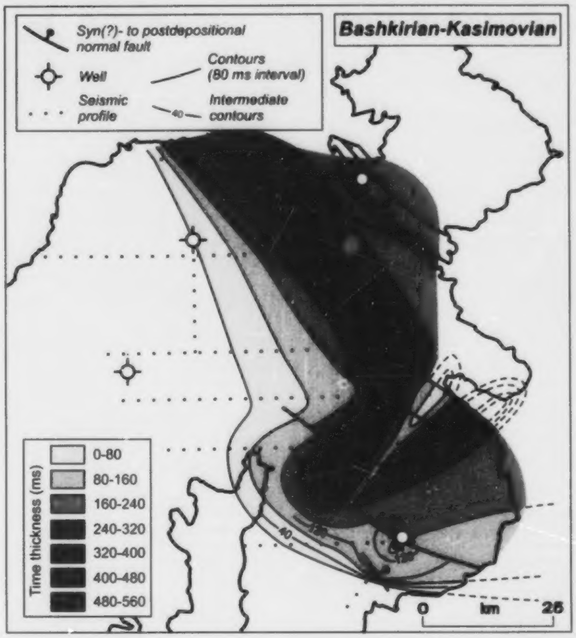

Figure 32. Isopach map of Bashkirian–Kasimovian Sequence. Time thickness is in milliseconds (ms).

Gzhelian–Sakmarian Sequence

The Gzhelian–Sakmarian Sequence comprises up to 480 ms (over 1.0 km) of clastics, carbonates, and mudrocks that belong to the Canyon Fiord (Upper clastic member), Belcher Channel, Nansen, and Hare Fiord formations. The sequence is irregularly distributed throughout Prince Patrick Island, reflecting extensive tectonic movement along a series of northwest–southeast-trending structures contemporaneous with its deposition (Fig. 33). Thickness variations are observed across most of the named northwest–southeast faults, but the most significant variations are recorded between the footwall (less than 80 ms) and hanging wall (more than 450 ms) of Jameson Fault-A (Fig. 24, 26, 33).

The upper portion of the Gzhelian–Sakmarian Sequence was penetrated by Jameson Bay C-31 and Satellite F-68. Fossils recovered from these wells enabled us to determine the age range of the sequence reasonably well. Abundant Gzhelian, Asselian, and Sakmarian fossils were recovered from that sequence throughout the eastern regions of the Sverdrup Basin (Henderson et al., 1995; Morin, 1992; Wallace et al., 1994; Rui et al, 1994; Henderson, 1989).

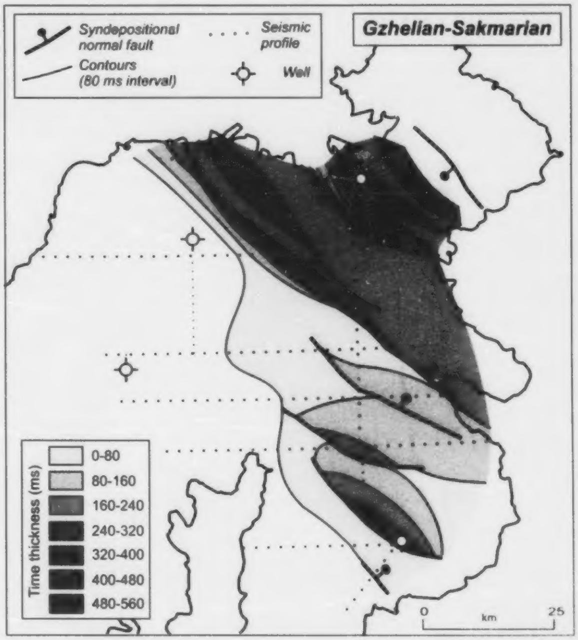

Figure 33. Isopach map of Gzhelian–Sakmarian Sequence. Time thickness is in milliseconds (ms).

Lower sequence boundary

The lower sequence boundary of the Gzhelian–Sakmarian Sequence is an unconformity, as is evidenced by the truncation of reflectors in the underlying sequence, as discussed previously. In addition, some reflectors at the base of the Gzhelian–Sakmarian Sequence appear to onlap this unconformity, such as immediately north of Moore Bay Fault-B (Fig. 24, 25) and possibly west of John Point Fault (Fig. 27). In the Sverdrup Basin, this unconformity roughly coincides with the Kasimovian–Gzhelian boundary (Henderson et al., 1995).

Upper sequence boundary

The upper sequence boundary is an unconformity and is present at 7293 ft. (2223 m) in Jameson Bay C-31 (Fig. 22), where it separates sandstone of the upper Belcher Channel Formation from shale of the lower Raanes Formation. This unconformity forms a toplap surface, shown by the updip truncation of Gzhelian to Sakmarian reflectors (Fig. 24, 25, 28, 29). In the Sverdrup Basin, this unconformity lies within the Sakmarian, as shown by rich assemblages of conodonts, fusulinaceans and small foraminifers (Beauchamp et al., 1998).

Maximum flooding surface

The maximum flooding surface of the Gzhelian–Sakmarian Sequence is marked by black, radioactive, organic-rich shale at 7583 ft. (2311 m) near the base of the Belcher Channel Formation in Jameson Bay C-31 (Fig. 22). This surface is truncated beneath the sub-Kungurian unconformity less than one kilometre north of Jameson Bay C-31 (Fig. 24) and hence cannot be readily traced seismically throughout Prince Patrick Island. The maximum flooding surface is questionably assigned to a prominent seismic horizon within the Gzhelian–Sakmarian Sequence, as observed in a number of profiles (Fig. 24–30). This horizon lies between a succession of closely spaced, laterally discontinuous weak reflectors below and more widely spaced, laterally continuous strong reflectors above. The rocks below this surface are believed to be a mixture of sandstone and carbonate, and perhaps even evaporites, whereas the rocks above the surface are likely dominated by carbonates. Throughout the Sverdrup Basin, significant lithological changes across the maximum flooding surface, such as the change from evaporites of the Mount Bayley Formation to carbonates of the Tanquary Formation on west-central Ellesmere Island (Morin et al., 1994; Wallace et al., 1994). The maximum flooding surface lies within the Asselian, as shown by a variety of fossils (Rui et al., 1994).

Transgressive systems tract

The Gzhelian–Asselian transgressive systems tract comprises a succession of fluvial, shoreface, and restricted-marine sandstones (Upper clastic member of Canyon Fiord Formation), shallow-water shelf limestone (Nansen Formation) and deep-water slope to basinal mudrock (Hare Fiord Formation) that accumulated in a series of active tectonic depressions bounded by northwest–southeast-trending faults (Fig. 33). Divergent reflectors indicative of structural growth and block rotation along these faults are observed in the hanging wall of the northeast-dipping Jameson Fault-A (Fig. 24) and in the hanging wall of the southwest-dipping Moore Bay Fault-B and -C (Fig. 24, 25). Significant syndepositional normal faulting, but without associated hangingwall block rotation, occurred along Hemphill Fault-C (Fig. 24, 25, 28). Minor normal fault motions are recorded across all of the other named faults (Fig. 24–30).

Evidence for additional deformation contemporaneous with the normal faulting is observed in seismic line 467 (Fig. 27). This evidence includes: 1) truncation of Kasimovian and older reflectors beneath the sub-Gzhelian unconformity over a broad anticline-like structure less than 10 km east of John Point Fault; 2) onlap of Gzhelian and/or younger reflectors onto that structure; 3) a more than fifty percent thinning of the Gzhelian–Sakmarian Sequence over that structure; and 4) possible inversion along NE Prince Patrick Fault-A and -B as shown by the concave-up attitude of reflectors within the Gzhelian–Sakmarian Sequence. Significant thinning (more than 50%) of the transgressive systems tract of the Gzhelian–Sakmarian Sequence is also observed between Joint Point Fault and Hemphill Fault-C in Figure 24, also suggesting the presence of an anticlinal-like structure between these faults.

The origins of the anticline-like structures between John Point Fault and Hemphill Fault-C and of the stratigraphic thinning above them are uncertain. Two possibilities are briefly considered here. The first is that the observed features are parallel to John Point Fault (northwest–southeast) and reflect the presence of a rollover anticline, which would have resulted from growth along John Point Fault and associated hanging wall block rotation. The second possibility is that the features in question are compressive in nature and lie at a high angle to John Point Fault, possibly parallel to the northeasterly trending basement high observed in the underlying Bashkirian–Kasimovian Sequence (Fig. 32). This second interpretation is further considered below under 'Geological history and paleogeography' and 'Regional and economic implications'.

Throughout the Sverdrup Basin, the Gzhelian–Asselian transgressive systems tract forms a complex facies mosaic deposited in a series of tectonic depressions that underwent episodic marine restriction. This mosaic comprises fluvial to marine sandstones (Upper clastic member of Canyon Fiord Formation), evaporites (upper Antoinette and Mount Bayley formations), and carbonates (Antoinette and Nansen formations) that pass basinward into slope-to-basinal mudrock (Hare Fiord Formation). These strata are typically arranged in a series of high-frequency sequences or cycles, which are difficult to correlate from place to place because of contemporaneous differential subsidence of tectonic origin (Morin, 1992). One tectonic depression west of the head of Trold Fiord, southwest Ellesmere (Beauchamp, 1987), comprises a succession of Gzhelian and Asselian fluvial, shoreface- to restricted-marine red shale, sandstone and minor limestone that is essentially identical to that penetrated by Jameson Bay C-31.

Regressive systems tract

The Asselian and Sakmarian regressive systems tract was penetrated by Jameson Bay C-31, where it forms an 88 m thick succession of shale and carbonate-shelf cycles (high-frequency sequences) that belong to the Belcher Channel Formation. Ten such cycles are present, the upper two of which are dominated by sandstone, reflecting a shallower, more proximal area of deposition.

In the more distal areas beyond the limit of drilling, the Asselian–Sakmarian regressive systems tract is assigned to continuous, widely spaced and strong reflectors that contrast sharply with the seismic expression of the underlying unit. Where observed with confidence, the seismically interpreted regressive systems tract forms a northeasterly thickening wedge that appears to postdate faulting in many areas. This is particularly obvious in Figures 24 and 25 (Hemphill Fault-A and -B), Figure 28 (Hemphill Fault-C), Figure 29 (Hemphill Fault-B and -C), and Figure 30 (Hemphill Fault-A and -B), where faults terminate beneath the assumed regressive systems tract. In contrast, significant thickness differences within the Asselian–Sakmarian regressive systems tract do occur between the footwall and hanging wall of John Point Fault and Hemphill Fault-C (Fig. 24, 25) and John Point Fault (Fig. 27). These differences, however, are believed to reflect postdepositional footwall erosion associated with a younger episode of faulting (see "Sakmarian–Artinskian Sequence" below).

In summary, the Asselian–Sakmarian regressive systems tract is believed to have formed a succession of open-marine carbonates that prograded basinward during a rest in fault activity. The wide carbonate platform that resulted from this process extended from south of Jameson Bay C-31 to somewhere midway between Hemphill Fault-A and Moore Bay Fault-A. Large carbonate buildups formed near the shelf-to-basin transition, as evidenced by the presence of reef debris in the correlative Hare Fiord Formation at Satellite F-68. Arched seismic reflectors between Hemphill Fault-A and Moore Bay Fault-A in Figures 24 and 25 may attest to the presence of such buildups.

In other parts of the Sverdrup Basin, the Asselian–Sakmarian regressive systems tract forms an easily correlatable, gently thickening succession of 10 to 12 open-marine shelf-carbonate cycles (Belcher Channel, Tanquary and Nansen formations) that contrast sharply with the underlying, highly complex, transgressive systems tract that recorded deposition in differentially subsiding tectonic depressions. The regressive systems tract, which is in general much thinner than its transgressive counterpart, passes basinward into shelf-edge reefal carbonate (upper Nansen Formation) and ultimately into slope to basinal mudrocks (upper Hare Fiord Formation), (Beauchamp et al., 1995a, c; Morin, 1992).

Sakmarian–Artinskian Sequence

The Sakmarian–Artinskian Sequence is composed of minor carbonates, mixed clastic-carbonate, sandstones, siltstones, and shales that belong to the Raanes, 'unnamed clastics' and Trappers Cove formations. The bulk of the sequence forms a broad depositional wedge that thickens from zero to more than 400 ms (probably more than 700 m) over 40 km in a northeasterly direction (Fig. 34). Local thickening of the sequence is observed in the hanging wall of Jameson Fault-A, John Point Fault, Hemphill Fault-C and -B (Fig. 34). The Sakmarian–Artinskian Sequence was encountered in Jameson Bay C-31, Andreasen L-32 and Satellite F-68 (Fig. 22, 23). The Sakmarian–Artinskian age range is relatively well constrained by fossil evidence. Abundant conodont and fusulinacean faunas have been recovered from this sequence throughout the Sverdrup Basin (Beauchamp and Henderson, 1994; Beauchamp et al., 1998).

Lower sequence boundary

The lower sequence boundary is an unconformity that was penetrated at 7293 ft. (2223 m) in Jameson Bay C-31, where it separates the Raanes and Belcher Channel formations (Fig. 22). The unconformity lies a few metres below the bottom of Andreasen L-32, where 'unnamed clastics' strata rest directly upon the Franklinian basement (Fig. 23). The unconformity is evidenced by the truncation of reflectors (toplap surface) in the underlying sequence. It also forms a surface that is onlapped by reflectors belonging to the Sakmarian–Artinskian Sequence, such as immediately north of Hemphill Fault-C (Fig. 24), south of Moore Bay Fault-A (Fig. 25), and east of John Point Fault (Fig. 27). The

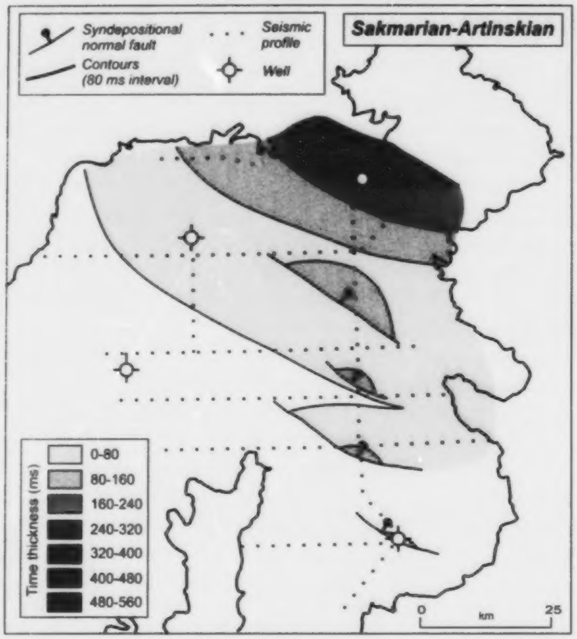

Figure 34. Isopach map of Sakmarian–Artinskian Sequence. Time thickness is in milliseconds (ms).

unconformity can be traced up to an area between Hemphill Fault-A and Moore Fault-A, beyond which the lower sequence boundary is believed conformable. This conformable surface lies just below the bottom of Satellite F-68. Where conformable elsewhere in the Sverdrup Basin, the lower sequence boundary lies within Sakmarian sediments (Beauchamp and Henderson, 1994; Beauchamp et al., 1998).

Upper sequence boundary

The upper sequence boundary is an unconformity that separates red shale of the Sabine Bay Formation from calcareous sandstone of the Raanes Formation at 7120 ft. (2170 m) in Jameson Bay C-31 (Fig. 22). The entire Sakmarian–Artinskian Sequence is completely eroded beneath the sub-Kungurian unconformity a short distance north of Jameson Bay C-31, in the hanging wall of Jameson Fault-A (Fig. 24, 26). It is also eroded beneath the mid-Permian unconformity just south of Hemphill Fault-C (Fig. 24). The upper sequence boundary lies at 6853 ft. (2089 m) in Andreasen L-32, where it is an unconformity that separates sandstone of the 'unnamed clastics' formation below and dark mudrock of the van Hauen Formation above (Fig. 23). The conformable sequence boundary lies at 10 130 ft. (3088 m) in Satellite F-68 within a siltier horizon of the Trappers Cove Formation (Fig. 22, 23). Throughout the Sverdrup Basin, the upper sequence boundary, where conformable, roughly coincides with the Artinskian–Kungurian boundary.

Maximum flooding surface

The maximum flooding surface is picked at 11 738 ft. (3578 m) in Satellite F-68, where black, organic-matter-rich, radioactive shales lie near the base of the Trappers Cove Formation (Fig. 22, 23). This surface can be traced seismically updip as far as between Moore Bay Fault-A and Hemphill Fault-A in the northern area, where it appears to onlap an apparently elevated underlying reflector that may or may not represent a carbonate buildup (Fig. 25). In the more southern areas, the maximum flooding surface can be traced as far south as Hemphill Fault-C (Fig. 24).

In the Sverdrup Basin, the maximum flooding surface roughly corresponds to the Sakmarian–Artinskian boundary and generally lies near the contact between the Raanes and Great Bear Cape formations (Beauchamp and Henderson, 1994; Kells, 1996; Kells et al., 1995; Scott, 1992).

Transgressive systems tract

The Sakmarian transgressive systems tract is composed of a succession of marine carbonates, mixed clastic–carbonate, and variably calcareous sandstone assigned to the Raanes Formation in the proximal areas. In the distal areas, the correlative succession comprises increasingly deep-water slope to basinal mudrock that lies within the upper part of the Hare Fiord Formation (Fig. 22, 23).

The transgressive systems tract was contemporaneous with a renewed phase of normal faulting along some of the northwest–southeast structures. This is shown by the hanging wall thickening and concomitant footwall thinning of the succession across Jameson Fault-A, John Point Fault, Hemphill Fault-C, and Hemphill Fault-B (Fig. 24–30, 34). Additional deformation of a possibly compressive nature is also evident east of John Point Fault, where thinning and onlap of Sakmarian strata occur over the same anticline-like structure documented under the previous sequence (Fig. 27). In addition, Sakmarian deposition appears to have been contemporaneous with a minor phase of reverse faulting along a steep fault offshoot of the underlying NE Prince Patrick Fault-A. The possible compressive origin of this structure will be examined below (see 'Geological history and paleogeography' and 'Regional and economic implications').

Throughout the Sverdrup Basin, the Sakmarian transgressive systems tract, the bulk of which is represented by the Raanes Formation, forms an irregularly distributed succession that thickens over short distances. The succession was deposited in variably subsiding tectonic depressions, all but the most basin-marginal of which remained fully interconnected by marine waters (see Scott, 1992).

Regressive systems tract

The Artinskian regressive systems tract forms a broad, tapering wedge that thickens from its erosional edge west of Andreasen L-32 (Fig. 23, 25) and north of Hemphill Fault-C (Fig. 24) to probably more than 500 m in the northern areas (Fig. 22, 23, 34). The shallowest portion of this wedge comprises fluvial, shoreface, and subtidal marine sandstone that passes basinward into shale and siltstone of the Trappers Cove Formation through a ramp-like transition. Progradation of this clastic wedge marks the end of carbonate sedimentation on Prince Patrick Island, the implications of which will be discussed below ('Regional and economic implications'). There is no evidence that faulting occurred during progradation because all faults terminate well below the wedge (Fig. 24, 25, 29, 30).

Throughout the Sverdrup Basin, the Artinskian regressive systems tract is represented by open-marine, cool-water carbonate of the Great Bear Cape Formation and correlative chert and mudrock of the Trappers Cove Formation. These sediments prograded basinward over large distances during a phase of passive subsidence (Beauchamp and Henderson, 1994; Kells, et al., 1995).

Kungurian Sequence

The Kungurian Sequence comprises up to 200 ms (about 140 m) of red shale and siltstone and variably conglomeratic sandstone that belong to the Sabine Bay Formation (Fig. 22). These sediments lie within an easterly trending oblong subbasin that covers more than 250 square km in the southern part of the study area (Fig. 35). The Kungurian Sequence displays a complex preservation within the subbasin, attesting to syndepositional folding and faulting (discussed below). A more than 200 m thick succession of shale, siltstone and minor sandstone that lies in the upper part of the Trappers Cove Formation and lower part of the van Hauen Formation is tentatively assigned to the Kungurian Sequence in the northern distal areas (Fig. 22, 23, 35).

This sequence is loosely assigned to the Kungurian interval based on indirect stratigraphic evidence and poorly constrained paleontological data. It forms a succession of mostly nonmarine strata irregularly distributed along the southern (Henrietta Nesmith Glacier, northern Ellesmere Island; Fosheim and Hamilton peninsulas, west-central Ellesmere Island; Sabine Peninsula, northeast Melville Island), and northern (Svartevaeg Cliffs, northern Axel Heiberg Island; Brock C-50 and I-20, Brock Island) margins of the Sverdrup Basin. In contrast, the sequence is seemingly absent on Raanes Peninsula, southwest Ellesmere Island, Grinnell Peninsula, northwest Devon Island and throughout northwest Ellesmere Island. The absence of the Kungurian Sequence in basin marginal areas in part reflects its erosion and/or nondeposition beneath the mid-Permian unconformity. The absence of a readily correlatable sequence in the more distal areas is problematic throughout the Sverdrup Basin, where strata of that age usually form a condensed interval that has been at times included in the transgressive systems tract of a broader Kungurian–Wordian Sequence (Beauchamp et al. 1995a).

Lower sequence boundary

The lower boundary of the Kungurian Sequence is a subaerial unconformity at 7120 ft. (2170 m) in Jameson Bay C-31. It juxtaposes fluvial overbank red shale and siltstone of the Sabine Bay Formation and marine calcareous sandstone of the underlying Raanes Formation (Fig. 22). This unconformity truncates increasingly older strata of the Sakmarian–Artinskian and Gzhelian–Sakmarian sequences north of Jameson Fault-A (Fig. 24).

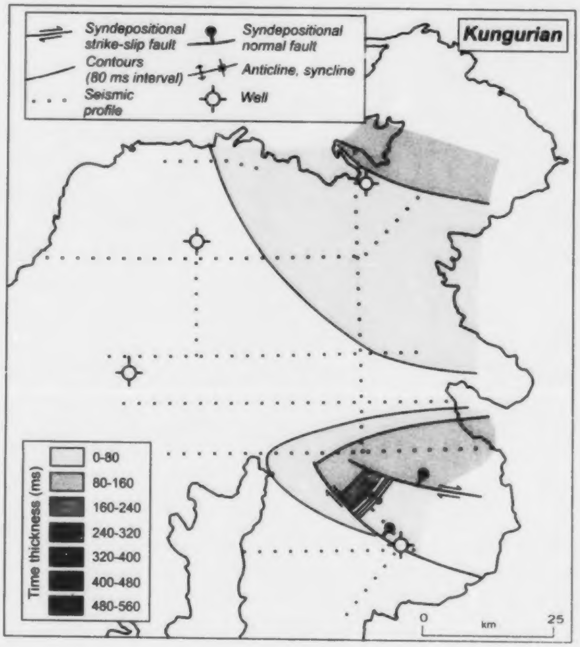

Figure 35. Isopach map of Kungurian Sequence. Time thickness is in milliseconds (ms).

Upper sequence boundary

The upper sequence boundary is an unconformity at 6680 ft. (2036 m) in Jameson Bay C-31. It lies between marginal-marine conglomeratic sandstone of the Sabine Bay below and deeper marine, dark-coloured shale and siltstone of the van Hauen Formation above (Fig. 22). This surface is an angular unconformity, herein referred to as the sub-Roadian or mid-Permian unconformity, and can be traced seismically as far as the environs of Hemphill Fault-B (Fig. 25). Beyond that point, the unconformity is traced into a conformable surface that intersects Satellite F-68 at 9465 ft. (2885 m) in the lower part of the van Hauen Formation (Fig. 22–25). The implication of this correlation is that the succession that lies between 9465 and 10 130 ft. (2885 and 3088 m) in Satellite Bay F-68 forms a sequence in the upper Trappers Cove and lower van Hauen formations in the distal area that is equivalent to the sequence represented by the Sabine Bay Formation in the proximal areas. This interpretation is plausible since a transgressive-regressive trend, albeit poorly defined, does occur within the 9465–10 130 ft. (2885–3088 m) interval in Satellite F-68 (Fig. 22, 23).

Regardless of its expression in the distal areas of the Sverdrup Basin, the mid-Permian unconformity constitutes a significant physical boundary within the upper Paleozoic succession, one that separates a lower succession that was deposited contemporaneous to various phases of faulting, from an upper succession that displays very little or no evidence of synsedimentary faulting. These two fundamental subdivisions are depicted schematically in a series of insets in Figures 24 to 30.

Maximum flooding surface

The maximum flooding surface of the Kungurian Sequence occurs at 6775 ft. (2065 m) in Jameson Bay C-31 (Fig. 22) where it coincides with a dark grey shale unit. This surface is truncated a short distance to the north beneath the sub-Roadian (mid-Permian) unconformity (Fig. 24). The maximum flooding surface coincides with the Trappers Cove–van Hauen contact at 9800 ft. (2987 m) in Satellite F-68 (Fig. 22–25). From that well it can be traced updip for some distance toward Moore Bay Fault-A, where it appears to onlap the underlying sequence boundary (Fig. 25).

Transgressive systems tract

In the distal areas, the transgressive systems tract of the Kungurian Sequence is assumed to lie in the upper part of the Trappers Cove Formation, as it does between 10 130 and 9800 ft. (3088 and 2987 m) in Satellite F-68 (Fig. 22, 23). This 99 m thick succession of deep-water slope to basinal shale and siltstone pinches out entirely just a few kilometres updip from Satellite F-68 (Fig. 25).

Most of the sequence is transgressive in the southern proximal areas. The sharp erosive surface at 6830 ft. (2082 m) in Jameson Bay C-31 is interpreted as a ravinement surface that separates fluvial red shale and siltstone below from marginal-marine conglomeratic sandstone associated with minor grey shale above (Fig. 22).

The lower part of the sequence comprises 88 m of nonmarine red shale and siltstone of the lower Sabine Bay Formation, interpreted as fluvial overbank strata. This succession is probably twice to three times as thick on either side of John Point Fault (Figs. 24, 27). The significant thickness of these floodplain sediments, as well as their fluvial origin, suggests that they accumulated in a rapidly subsiding, basin-marginal depression. Their very fine grained composition further suggests that very little relief surrounded the subbasin where they were deposited. These observations point to an episode of differential subsidence prior to the phase of active faulting that accompanied later Kungurian sedimentation.

Variably thick successions of fine-grained, red overbank strata consistently occur at the base of the Sabine Bay Formation on Fosheim and Hamilton peninsulas, west-central Ellesmere Island. More than 160 m of such sediments, associated with numerous paleosols, are known to occur at one locality on the west shore of Canyon Fiord (Beauchamp, unpublished observations). These fine-grained, red strata are invariably overlain by conglomeratic sandstone and conglomerate, attesting to a significant change in the depositional regime during deposition of the Kungurian Sequence.

The upper part of the transgressive systems tract at Jameson Bay C-31 comprises fluvial and shoreface, medium- to coarse-grained sandstone, conglomeratic sandstone and chert- and limestone-pebble conglomerate. The presence of locally derived coarse material, including upper Paleozoic limestone pebbles and fusulinaceans, is indicative of a sedimentary regime very different than that prevailing during deposition of the underlying succession. This regime is believed to have resulted from a brief yet significant phase of compressive deformation known as the Melvillian Disturbance.

The best evidence of compressive deformation on Prince Patrick Island is seen between Jameson Fault-A and John Point Fault, where an anticline formed during deposition of the upper Sabine Bay Formation (Fig. 24). This anticline is one of probably many fault-related topographic highs that segregated the low gradient, yet rapidly subsiding, floodplain into smaller depocentres. It is these smaller depocentres that received the much coarser, locally derived sandstone and conglomerate contained in the upper part of the Sabine Bay Formation. Reflectors in the lower part of the Sabine Bay Formation on the northern limb of the anticline south of John Point Fault appear to be folded as well, providing additional evidence that the lower red unit was deposited prior to the deformation (Fig. 24).

Limited seismic information in the study area prevents a definitive assessment of the Kungurian structural configuration, which is of paramount importance for deciphering the kinematic evolution of the Melvillian Disturbance on Prince Patrick Island. Some lines of evidence, however, do suggest that the compressive deformation was southeast directed (Fig. 35; see also 'Regional and economic implications'):

1. The anticline shown in Figure 24 appears to be spatially related to NE Prince Patrick Fault-B, that is, the northeast–southwest-trending normal fault assumed to be responsible for significant thickness variations in the Bashkirian–Kasimovian Sequence.

2. There is no evidence of thickness variations, and therefore of structural inversion, along the northwest–southeast-trending John Point Fault (Fig. 24, 27). Reflectors within the Kungurian Sequence appear disturbed, but not vertically displaced, across John Point Fault in Figure 24 (but not in Fig. 27) suggesting that strike–slip motions may have occurred along the fault.

3. Normal motions (and perhaps dextral strike–slip motion as well) are recorded along the northwest–southeast-trending Jameson Fault-A.

4. Broad undulations resulting in locally significant thickness variations in the upper part of the Kungurian Sequence are recorded all along seismic line 467 (Fig. 27). The axes of these undulations appear to be at a high angle to John Point Fault since they do not intercept the adjacent north–south seismic lines 468 and PPA5 (Fig. 24).

5. Detailed structural studies on nearby Melville Island have shown that mid-Permian structures associated with the Melvillian Disturbance resulted from a phase of southeast-directed compression (Harrison, 1995).

In the proximal areas, the upper part of the transgressive systems tract of the Kungurian Sequence is interpreted as comprising a complex mosaic of shallow subtidal, shoreface and braided river sandstone and minor shale. Wherever present at the margin of the Sverdrup Basin, the upper Sabine Bay Formation comprises buff-weathering sandstone and conglomerate of fluvial to marginal-marine origin. Fluvial overbank strata are invariably black and coaly, attesting to a significant climatic change from arid (red) to humid (black) conditions. (Beauchamp, 1994).

Regressive systems tract

The regressive systems tract of the Kungurian Sequence at Jameson Bay C-31 is only 29 m thick and comprises shoreface, medium- to coarse-grained sandstone, conglomeratic sandstone and chert- and limestone-pebble conglomerate. This succession pinches out entirely beneath the mid-Permian unconformity just a few kilometres to the north (Fig. 24). The assumed correlative succession in the distal area forms a relatively thin (101 m) wedge of deep-water shales and siltstones encountered in the lowest part of the van Hauen Formation at Satellite F-68 (Fig. 22, 23). The wedge pinches out updip beneath the Roadian–Wordian Sequence near Hemphill Fault-B (Fig. 25).

Roadian–Wordian Sequence

The Permian succession that lies between the mid-Permian unconformity and the sub-Triassic unconformity is Guadalupian in age, comprising Roadian, Wordian, and likely Capitanian strata as discussed under 'Trold Fiord Formation'. The Guadalupian succession forms a broad wedge of clastic strata that comprises three distinct lithological units (Fig. 38): 1) a lower, highly reflective, shale-dominated unit represented mostly by the van Hauen Formation and the lower part of Trold Fiord Formation; 2) a middle, poorly reflective, sandstone-dominated unit represented by the bulk of the Trold Fiord Formation; and 3) an upper, more reflective, shale-dominated unit represented by the upper part of the Trold Fiord Formation. A major unconformity lies within the Guadalupian succession separating a Roadian–Wordian Sequence below from a Capitanian(?) Sequence above (Fig. 39). This unconformity corresponds to a poorly reflective surface that can be traced with difficulty within the middle sandstone-dominated unit from Jameson Bay C-31 to Satellite F-68 (seismic surface 5 in Fig. 38, 39).

The Roadian–Wordian Sequence forms a wedge of clastic units that thickens in a northeasterly direction from its zero-edge west of Andreasen L-32 and Jameson Bay C-31 to more than 650 m in the environs of Satellite F-68 (Fig. 22, 23). Depositional trends inferred from isopachs suggest that the Roadian–Wordian clastic depositional system formed a broad lobe that is twice as wide in the central regions of the study area than it is at the northern and southern periphery of Prince Patrick Island (Fig. 36). There is no evidence of fault activity during deposition of the sequence, which is assigned with confidence to the Roadian–Wordian interval based on diagnostic palynofloras. The Roadian–Wordian Sequence comprises five, higher order, short-term sequences (sequences G1 to G5 in Fig. 39), the boundaries of which are evidenced by shifts in well log signatures. Two of these minor sequence boundaries correspond to surfaces that can be traced seismically between Jameson Bay C-31 and Satellite F-68 (seismic surfaces 3 and 4 in Fig. 38, 39). The highest of these minor sequence boundaries (seismic surface 4) appears to pinch out beneath the sub-Capitanian(?) unconformity, defining a toplap surface.

Throughout the Sverdrup Basin, strata of the Roadian–Wordian succession are found in the Assistance and Trold Fiord formations in the proximal areas and in the van Hauen and Degerböls formations in the distal areas (Beauchamp et al., 1995a, 1998).

Lower sequence boundary

The lower sequence boundary is an unconformity that juxtaposes the Trold Fiord Formation and the Franklinian basement at 4430 ft. (1350 m) in Intrepid Inlet H-49 (Fig. 23), the van Hauen and the 'unnamed clastics' formations at 6853 ft. (2089 m) in Andreasen L-32 (Fig. 23), and the van Hauen and the Sabine Bay formations at 6680 ft. (2036 m) in Jameson Bay C-31 (Fig. 22). The sequence boundary is conformable in Satellite F-68, where it lies at 9465 ft. (2885 m). As discussed under the previous heading, the sub-Roadian (mid-Permian) unconformity and its assumed correlative conformity in the distal areas is a significant marker throughout Prince Patrick Island. It is depicted schematically in the insets of Figures 24 to 30.

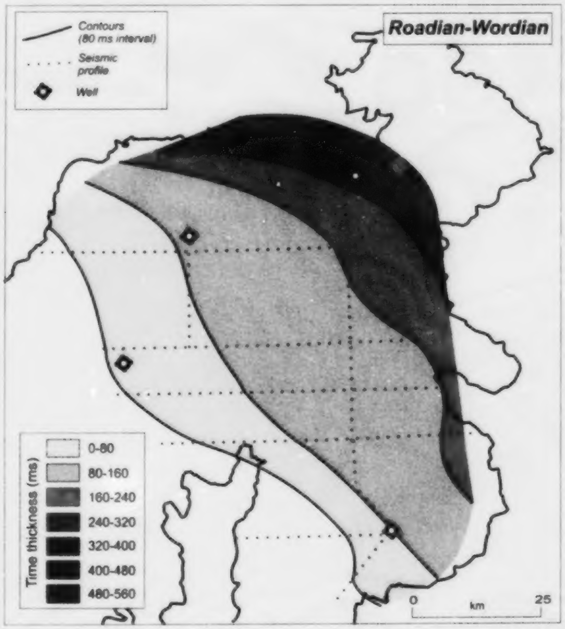

***Figure 36.** Isopach map of Roadian–Wordian Sequence. Time thickness is in milliseconds (ms).*

Upper sequence boundary

The upper sequence boundary is an unconformity encountered at 4260 ft. (1298 m) in Intrepid Inlet H-49, where conglomerate associated with siltstone and coal rest sharply upon calcareous sandstone and grey shale (Fig. 23). The unconformity is picked at 6130 ft. (1868 m) in Andreasen L-32 and at 5920 ft. (1804 m) in Jameson Bay C-31 near the top of prominent sandstone units (Fig. 22, 23). From these wells, this surface is traced seismically up to Satellite F-68, where it correlates into a probably conformable horizon at the top of a massive sandstone unit (Fig. 22–25).

Maximum flooding surface

The maximum flooding surface of the Roadian–Wordian Sequence, which occurs at 6580 ft. (2006 m) in Jameson Bay C-31 and 9320 ft. (2841 m) in Satellite F-68, can be readily traced seismically between the two wells because it lies just beneath a strong, laterally continuous reflector. In both wells, the maximum flooding surface is evidenced by its gamma-ray and sonic velocity signature, which reflect the presence of dark, organic-rich shale. This surface terminates east of Intrepid Inlet H-49 and Andreasen L-32 in the northern areas (Fig. 23). Throughout the Sverdrup Basin, the maximum flooding surface roughly coincides with the Roadian–Wordian boundary (Beauchamp et al., 1995a, 1998).

Transgressive systems tract

The Roadian transgressive systems tract comprises a thin succession of dark grey to black shale and siltstone that lie in the lower part of the van Hauen Formation. This succession is just over 30 m thick at Jameson Bay C-31 (Fig. 22) and about 44 m thick in Satellite F-68 (Fig. 22, 23). A much thicker transgressive succession is observed in the easternmost portion of seismic line 467, where a seismic unit up to 100 ms thick onlaps the sub-Roadian unconformity in a westerly direction (Fig. 27). It is plausible that this unit is represented by marine sandstone of the Assistance Formation, which was not penetrated by any of the Prince Patrick wells but is known to occur on nearby Melville Island as well as all along the southern margin of the Sverdrup Basin (Harrison, 1995; Thorsteinsson, 1974; Beauchamp et al., 1998; Mayr, 1992). The Assistance Formation is a well-dated Roadian unit of fossiliferous sandstone (Fig. 3). The Assistance Formation is overlain by either the van Hauen Formation, such as on Raanes Peninsula, southwest Ellesmere Island; or the Degerböls Formation, such as on Sabine Peninsula, northeast Melville Island; or the Trold Fiord Formation, such as on Fosheim and Hamilton peninsulas, west-central Ellesmere Island.

Regressive systems tract

A more than 700 m thick succession of shallowing-upward, progradational, open-marine shale, siltstone and sandstone constitutes the bulk of the Wordian regressive systems tract. These strata belong to the van Hauen Formation and lower part of the Trold Fiord Formation (Fig. 22–25). The absence of clinoforms between the proximal and distal areas suggests a gentle ramp-like transition between the shallower and deeper water areas. The Wordian regressive systems tract comprises five, high-order, short-term sequences (sequences G1 to G5 in Fig. 39), the uppermost of which (sequence G5) appears to be truncated beneath the sub-Capitanian(?) unconformity just north of Jameson Bay C-31 (Fig. 38, 39).

Throughout the Sverdrup Basin, the Wordian succession is invariably regressive, progradational, and comprises a series of prominent cycles or higher-order sequences nested within it. The contents of these sequences vary greatly from place to place (Beauchamp et al., 1989a, b, 1995a, 1998; Harrison, 1995). At one end of the spectrum are the areas that received little or no coarse clastic material, such as Hvitland Peninsula, northwest Ellesmere Island, where fossiliferous cyclic carbonate of the Degerböls Formation passes into spiculitic chert of the van Hauen Formation. At the other end of the spectrum are the areas that received large volumes of coarse, terrigenous material, such as Hamilton and Fosheim peninsulas, west-central Ellesmere Island, where sandstone of the Trold Fiord Formation passes directly into shale and siltstone of the van Hauen Formation with little or no intermediate carbonate. In between are the areas that received a fair amount of clastic material but not enough to smother carbonate and spiculitic sedimentation completely. Raanes Peninsula, southwest Ellesmere (Beauchamp, 1987) and Sabine Peninsula, northeast Melville Island (Harrison, 1995) are two such areas, where complex facies relationships between the Trold Fiord, Degerböls, and van Hauen formations occur over relatively short distances.

Prince Patrick Island was obviously an area of significant clastic influx as is shown by the paucity of biogenic, carbonate-secreting material in the Trold Fiord Formation and siliceous sponge spicules in the van Hauen Formation. These observations, coupled with the great thickness of the Trold Fiord Formation and its much lower concentration of glauconitic material – an indicator of slow sedimentation – compared to other areas, suggest that Prince Patrick Island was the entry point of a major river system in the Sverdrup Basin. The relative abundance of well-preserved wood debris in the Trold Fiord Formation – a rare feature elsewhere in the Sverdrup Basin – also suggests a high rate of sedimentation conducive to the preservation and rapid burial of these fragile elements. The lobate planar configuration of the Roadian–Wordian depositional system (Fig. 36) is suggestive of a broad, low-gradient, deltaic clastic apron, one that was wave-dominated, and where sediments carried into the sea were quickly redistributed on a gently sloping ramp through marine processes. The high chert content (15 to 40%) of Trold Fiord sandstone further suggests that the clastic sediments were of relatively local, basin-fringing, derivation.

Capitanian(?) Sequence

The Capitanian(?) Sequence forms a broadly transgressive, increasingly shaly wedge of clastic strata that thickens from its zero-edge, which lies just west of Intrepid Inlet H-49 and more than 30 km west of Jameson Bay C-31, to probably more than 400 m east and northeast of Satellite F-68 (Fig. 22, 23, 37–39). Local thickening and thinning of the sequence is observed west and southwest of Jameson Bay C-31 (Fig. 24, 26), the significance of which is discussed below (see 'Transgressive systems tract').

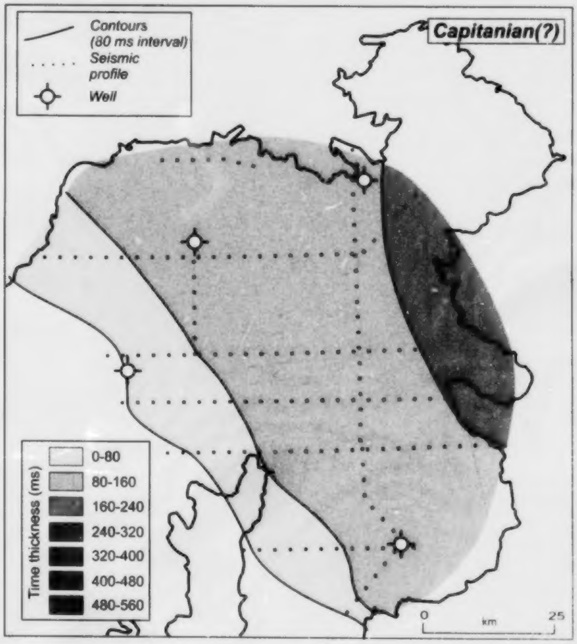

Figure 37. Isopach map of Capatanian(?) Sequence. Time thickness is in milliseconds (ms).

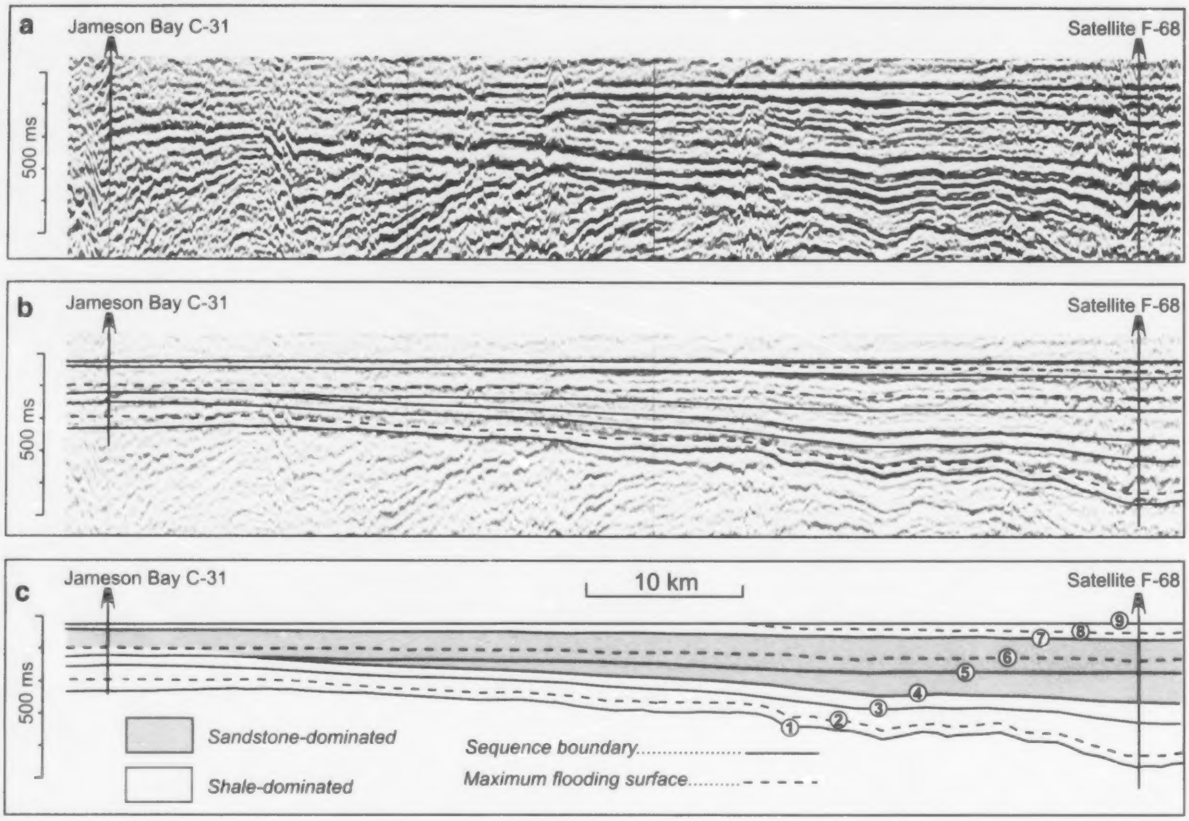

Figure 38. *Guadalupian succession on composite seismic profile C31F68, flattened to base Triassic.* ***a.*** *Uninterpreted profile.* ***b.*** *Sequence statigraphic interpretation.* ***c.*** *Sequence statigraphic interpretation in relation to sandstone- and shale-dominated portions of Guadalupian succession. Surfaces 1 to 6 in* ***c*** *correspond to surfaces correlated in Figure 39.*

The Capitanian(?) Sequence comprises three higher-order sequences (sequences G6 to G8 in Fig. 39), the boundaries of which are suggested by well log signatures. One of these minor sequence boundaries corresponds to seismic surface 7 (Fig. 38, 39). Two additional seismic surfaces (surfaces 6 and 8) roughly coincide with the maximum flooding surfaces of sequences G6 and G8 (Fig. 38, 39).

Lower sequence boundary

As discussed under the previous sequence, the lower sequence boundary is an unconformity within the Trold Fiord Formation that was penetrated at 4260 ft. (1298 m) in Intrepid Inlet H-49, 6045 ft. (1843 m) in Andreasen L-32, and 5920 ft. (1804 m) in Jameson Bay C-31 (Fig. 22, 23). The correlative, and assumed conformable, horizon in the distal areas is picked at 7310 ft. (2228 m) in Satellite F-68 (Fig. 22, 23).

Upper sequence boundary

The upper sequence boundary is the contact between the Permian Trold Fiord Formation and the overlying Lower Triassic Bjorne Formation. This formational contact is an unconformity that extends beyond Satellite F-68 and probably a fair distance farther to the northeast. In Jameson Bay C-31, the unconformity juxtaposes grey shale and minor sandstone of the Trold Fiord Formation and sandstone and grey marine shale of the Bjorne Formation (Fig. 22). In Andreasen L-32, the unconformity lies between Trold Fiord sandstone and minor shale and Bjorne red and grey shale and sandstone (Fig. 23). In Satellite F-68, relatively clean sandstone of the Trold Fiord Formation is sharply overlain by a thin unit of grey shale and minor sandstone that lies at the base of the Bjorne Formation.

Seismically, the sub-Triassic unconformity is a sharp surface that separates the poorly reflective Bjorne succession from the far more reflective upper Trold Fiord succession.

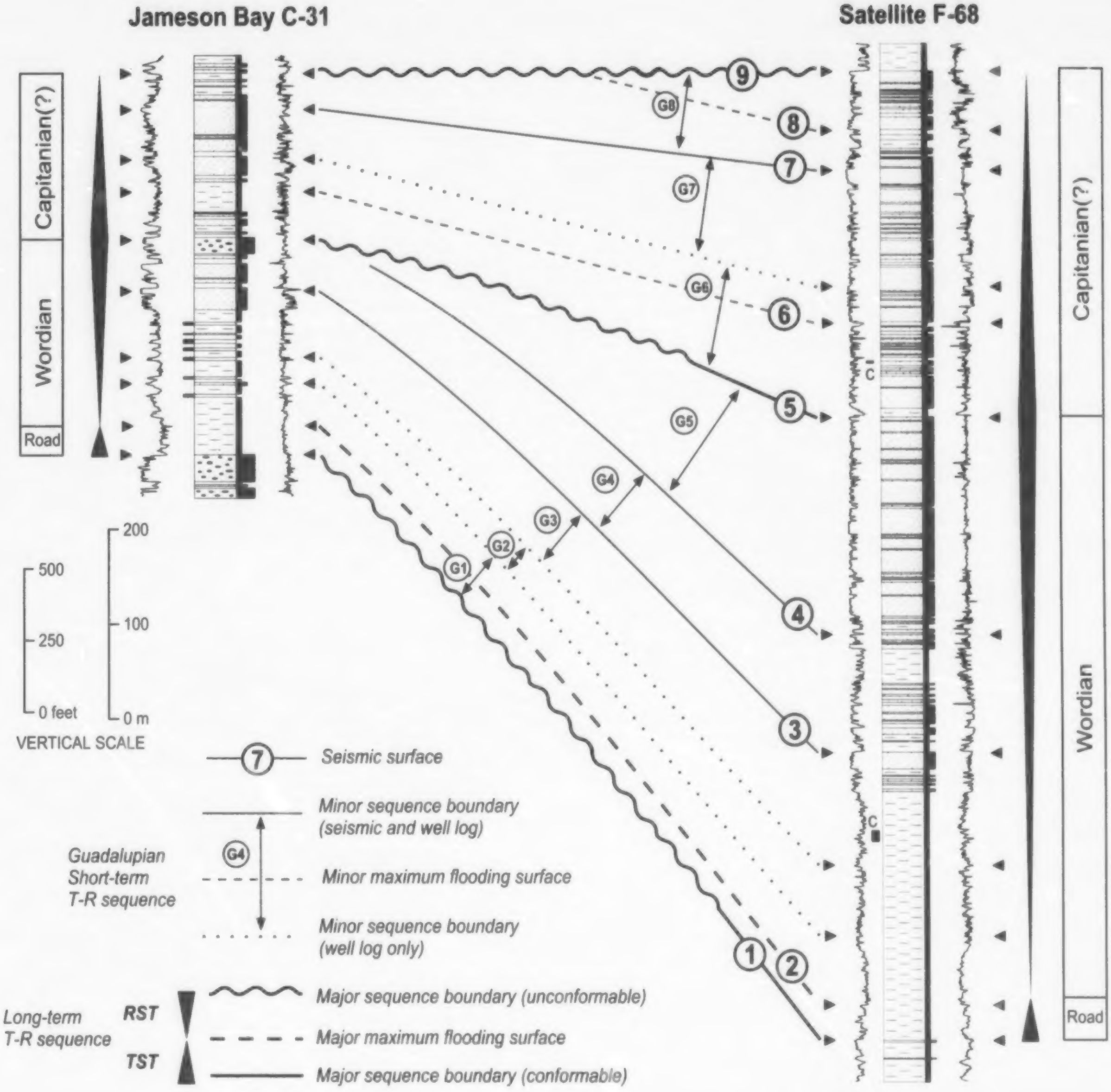
Jameson Bay C-31
Satellite F-68
Capitanian(?)
Wordian
Road
9
8
7
6
5
4
3
2
1
G1
G2
G3
G4
G5
G6
G7
G8
C
200
100
0 m
500
250
0 feet
VERTICAL SCALE
Seismic surface
Minor sequence boundary (seismic and well log)
Guadalupian Short-term T-R sequence
Minor maximum flooding surface
Minor sequence boundary (well log only)
Long-term T-R sequence
RST
TST
Major sequence boundary (unconformable)
Major maximum flooding surface
Major sequence boundary (conformable)

Figure 39. *Guadalupian correlations between Jameson C-31 and Satellite F-68 showing major sequence boundaries (surfaces 1, 5, and 9) and intervening Roadian–Wordian and Capitanian(?) sequences as well as minor sequence boundaries and associated short-term sequences (G1 to G8) nested within the long-term sequences. Note pinchout of sequence G5 beneath sub-Capitanian(?) unconformity. For lithological key see Figure 6.*

This surface is onlapped by a whole series of reflectors in the Bjorne Formation (Fig. 24–30).

Transgressive systems tract

The Capitanian(?) Sequence lies within the Trold Fiord Formation and comprises a succession of sandstone and shale that becomes increasingly shaly upward (Fig. 38). This is indicative of a progressive retrogradation of the Guadalupian clastic depositional system during the Capitanian(?), and hence the entire sequence is considered broadly transgressive (Fig. 22, 23, 39). The widespread sub-Triassic unconformity truncates the top of the Capitanian(?) transgressive systems tract throughout the study area. The regressive systems tract may or may not be present in the more distal areas, such as near Ballantyne Strait.

Significant thickness variations occur locally within the lower portion of the Capitanian(?) transgressive systems tract in the southern regions of the study area (Fig. 24, 26, 38, 39). Reflectors within the succession appear to be truncated updip, locally defining a toplap surface (Fig. 26). It may be significant that this surface (seismic surface 6 in Fig. 38) correlates with the maximum flooding surface of a short-term, high-order sequence (sequence G6 in Fig. 39). This surface correlates with an up to 50 per cent organic-rich, coaly shale with source rock potential at 4230 ft. (1289 m) in Intrepid H-49, 6045 ft. (1843 m) in Andreasen L-32, and 7000 ft. (2134 m) in Satellite F-68 (see 'Economic potential'). The widespread occurrence of such an organic-rich horizon suggests that the study area underwent some form of starvation; that is, a significant pause in the influx of clastic material. The association of this horizon with significant thickness variations and possibly local truncations within the underlying succession may be indicative of differential subsidence associated with some form of tectonism during the early part of the Capitanian(?).

Throughout the Sverdrup Basin, the Capitanian(?) succession is also broadly transgressive and characterized by a series of high-order sequences of increasingly deep-water origin. The Capitanian(?) time interval was invariably associated with the widespread retrogradation of clastic (Trold Fiord Formation) and carbonate (Degerböls Formation) depositional systems. As in Prince Patrick Island, the subsequent regressive systems tract is typically absent beneath the sub-Triassic unconformity in the proximal areas. In the more distal areas, the regressive systems tract comprises a shallowing-upward succession of spiculitic chert and minor sandstone that forms the bulk of a new formation to be defined in a future publication (Fig. 3).

GEOLOGICAL HISTORY AND PALEOGEOGRAPHY

The geological history of Prince Patrick Island is depicted in a series of paleogeographic maps (Fig. 40–51). These maps are based upon the information derived from the four wells that penetrated upper Paleozoic strata (Intrepid Inlet H-49, Jameson Bay C-31, Andreasen L-32, and Satellite F-68), from the nearly 430 km of seismic lines used in this study, and from a wealth of stratigraphic and structural knowledge from other subsurface and surface areas of the Sverdrup Basin. Albeit imperfect, and in places speculative because of the limitations of the database, these maps provide the most plausible synthesis of the observations and interpretations contained in the previous sections of this chapter.

Serpukhovian(?)

An episode of rifting affected the northern regions of Prince Patrick Island during Serpukhovian time (Fig. 40). Crustal extension and block rotation occurred in opposite directions along the northwest-trending Hemphill Fault-A and Moore Bay Fault-A resulting in two half-grabens of opposite polarity separated by a narrow accommodation zone (uplift). It is believed that the graben fills are composed of alluvial fan and braided river conglomerate and sandstone, the coarsest material of which was derived from the nearby fault escarpments (Fig. 40). These sediments are assumed to belong to the Borup Fiord Formation and thus to be of Serpukhovian age.

Bashkirian

A second pulse of rifting affected Prince Patrick Island during the Bashkirian (Fig. 41). Crustal extension and block rotation occurred along two, gently dipping, northeast-trending normal faults: NE Prince Patrick Fault-A and -B. Two half-grabens bounded by basement highs developed along the faults. Alluvial fan and braided river conglomerate and sandstone likely accumulated during an early phase of graben development (Fig. 41). Marine waters later invaded

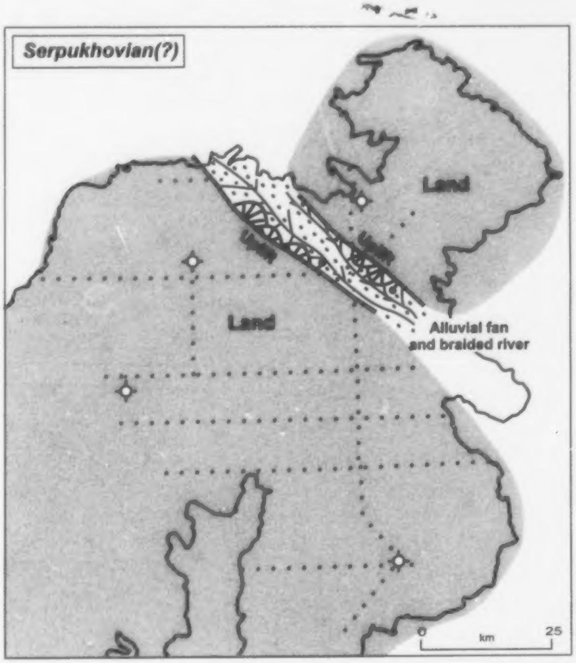

Figure 40. Serpukhovian(?) paleogeography.

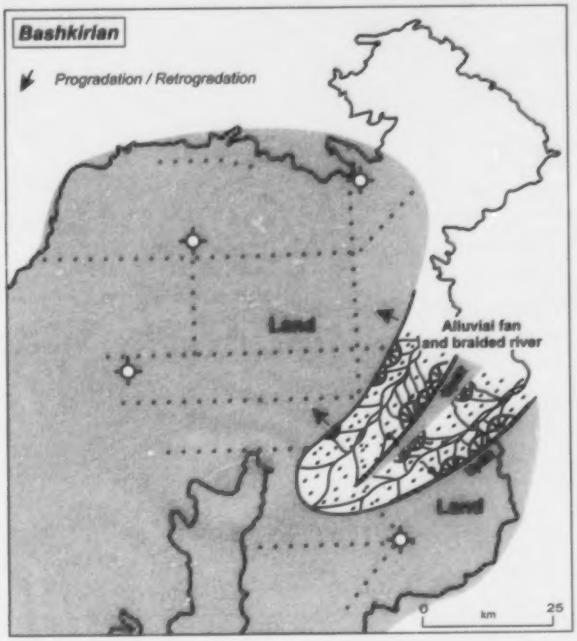

Figure 41. Bashkirian paleogeography.

the grabens from the northeast. The nonmarine to marine graben fills are assumed to be Bashkirian in age and to belong to the Lower clastic member and possibly basal part of the Middle limestone member of the Canyon Fiord Formation. These rocks form the bulk of the transgressive systems tract of the Bashkirian–Kasimovian Sequence.

Moscovian–Kasimovian

A long episode of apparent tectonic quiescence and passive subsidence affected the study area during the Moscovian–Kasimovian time interval (Fig. 42). As a result, a broad carbonate shelf developed and prograded in a northeasterly direction. Shallow- to deep-water, tropical, fossiliferous shelf carbonate passes into deeper water, slope to basinal, argillaceous limestone, debris flows and mudrock. Variably sized carbonate buildups likely developed at the shelf-edge. These carbonates belong to the Middle limestone member of the Canyon Fiord Formation and correlative parts of the Nansen Formation. The distal mudrock is part of the Hare Fiord Formation. This progradational succession forms the regressive systems tract of the Bashkirian–Kasimovian Sequence. Many high-frequency sequences are superimposed on the long-term regressive trend.

Gzhelian–Asselian

Tectonic activity resumed during the Gzhelian and early part of the Asselian (Fig. 43). Crustal movements led to significant normal faulting, block rotation and footwall uplift along the southwest-dipping Moore Fault-A, -B and -C and on the northeast-dipping Jameson Fault-A. Varying normal motions, without significant block rotation, also occurred along Jameson Fault-B, John Point Fault, and Hemphill Fault-A, -B and -C. Contemporaneous uplift, perhaps associated with reverse motion along the northwest-dipping NE Prince Patrick Fault-A and -B, appears to have affected strata contained in the hanging wall of John Point Fault. The various tectonic depressions that resulted from differential fault-controlled subsidence remained interconnected by marine waters during the Gzhelian–Asselian interval, except for possible brief episodes during their earliest stages of development.

The Gzhelian–Asselian paleogeography was characterized by a broad, sandstone-dominated, shallow-water shelf that passed distally into a narrower, carbonate-dominated shelf and ultimately into deeper water slope to basinal mudrock (Fig. 43). Fluvial sandstone and overbank shale were deposited in the more proximal areas following the episodic retreat of the sea associated with high-frequency cycles. Overall, the Gzhelian–Asselian succession is

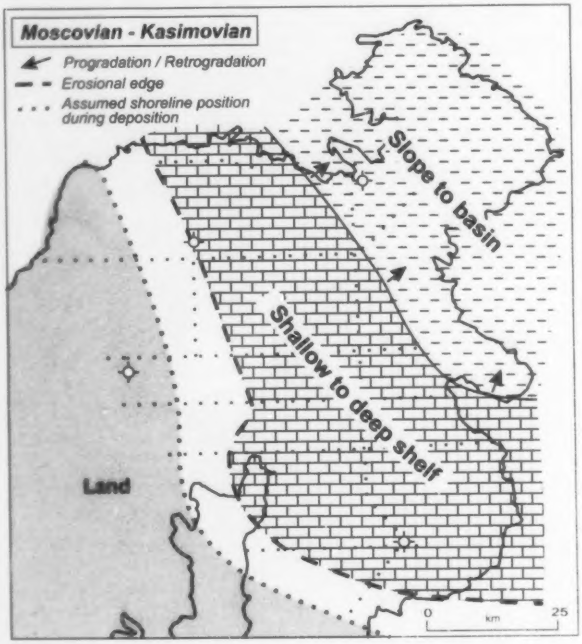

Figure 42. Moscovian–Kasimovian paleogeography.

indicative of a progressive, southwest-directed inundation of the craton. These strata thus constitute the transgressive systems tract of the Gzhelian–Sakmarian Sequence, which is represented by clastics of the Upper clastic member of Canyon Fiord Formation, carbonate of the Nansen Formation and mudrock of the Hare Fiord Formation.

Asselian–Sakmarian

Tectonic activity and associated fault movements ceased during the Asselian (Fig. 44). A regime of passive subsidence followed, allowing shelf carbonates to prograde basinward for some distance. Shallow- to deep-water, tropical, fossiliferous carbonate accumulated over a wide area during the later part of the Asselian and early part of the Sakmarian. Shelf-edge carbonate formed in the distal areas. Slope to basinal mudrock and carbonate debris flows shed from the shelf were deposited in the northeastern areas. The fossiliferous carbonate belongs to the Belcher Channel and upper Nansen formations. The correlative mudrock occurs in the upper part of the Hare Fiord Formation. These sediments form the regressive systems tract of the Asselian–Sakmarian Sequence.

Sakmarian

Tectonic activity resumed during the latter part of the Sakmarian resulting in fault-controlled differential subsidence along segments of Hemphill Fault-B and -C, John Point Fault and Jameson Fault-A (Fig. 45). Contemporaneous uplift and folding, possibly associated with reverse movements along NE Prince Patrick Fault-A and -B also occurred north and east of John Point Fault. The

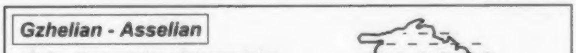
Gzhelian - Asselian
Progradation / Retrogradation
Erosional edge
Assumed shoreline position during deposition
Slope to basin
Shallow to deep shelf
Fluvial, shoreface and shallow subtidal
Land
0
km
25

Figure 43. Gzhelian–Asselian paleogeography.

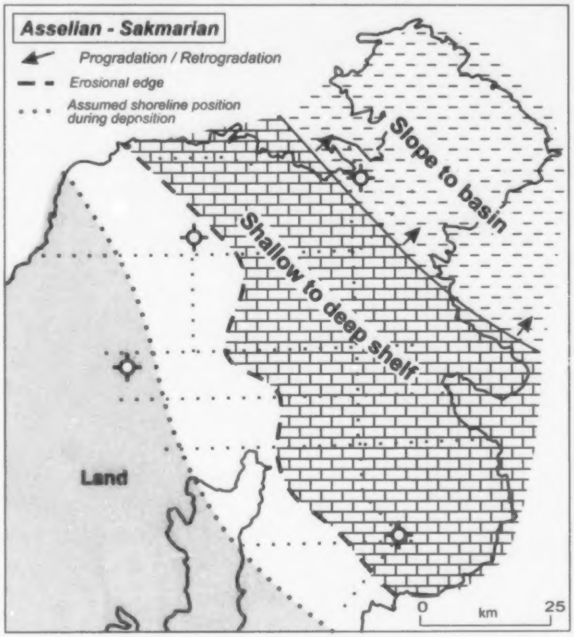

Figure 44. Asselian–Sakmarian paleogeography.

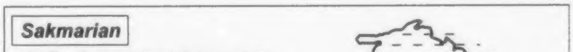
Sakmarian
Progradation / Retrogradation
Erosional edge
Assumed shoreline position during deposition
Slope to basin
Shallow to deep ramp
Land
0
km
25

Figure 45. Sakmarian paleogeography.

late Sakmarian paleogeography of the area was characterized by a shallow- to deep-water mixed ramp of clastic and carbonate sediments (Raanes Formation) passing basinward into deeper water slope to basinal mudrock (uppermost Hare Fiord Formation). These sediments form the transgressive systems tract of the Sakmarian–Artinskian Sequence.

Artinskian

Faulting ceased once again during the Artinskian and a regime of passive subsidence was established (Fig. 46). A broad clastic ramp developed, fed by a large, extrabasinal river system that brought volumes of chert-rich sand from a major terrigenous source to the south and southwest. The onset of this depositional pattern marks the end of carbonate sedimentation on Prince Patrick Island. The clastic ramp comprises marine sandstone and coarse siltstone of the 'unnamed clastics' formation, which pass basinward into deep-water, slope to basinal shale and fine siltstone of the Trappers Cove Formation. These rocks constitute the regressive systems tract of the Sakmarian–Artinskian Sequence.

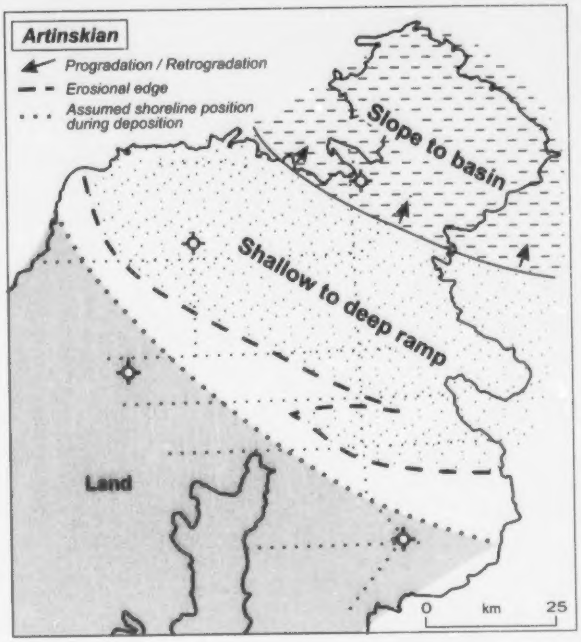
Artinskian
Progradation / Retrogradation
Erosional edge
Assumed shoreline position during deposition
Slope to basin
Shallow to deep ramp
Land
0
km
25

Figure 46. *Artinskian paleogeography.*

Kungurian (early)

A large nonmarine subbasin developed in the southern areas during the Kungurian time interval (Fig. 47). The bulk of the subbasin fill comprises red shale and siltstone that were deposited in a rapidly subsiding floodplain isolated from the sea to the north, where a thin condensed succession of shale and siltstone accumulated at the same time.

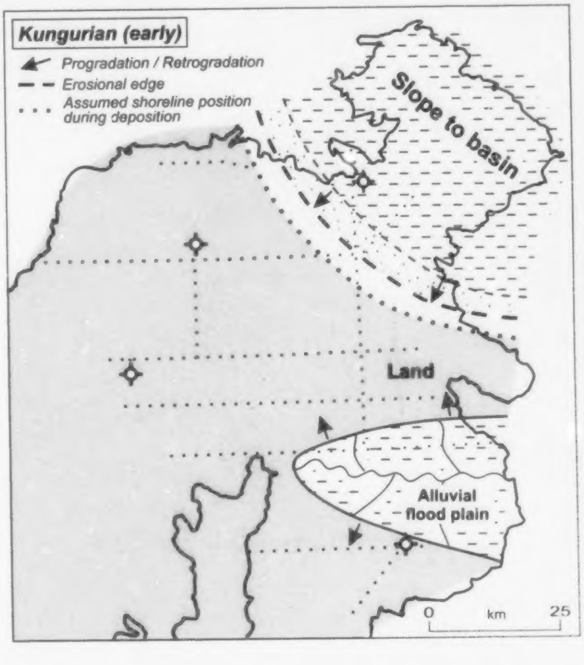

Figure 47. *Kungurian (early) paleogeography.*

Kungurian (late)

Tectonic activity (Melvillian Disturbance) took place later during the Kungurian (Fig. 48). Normal motion along John Point Fault and Jameson Fault-A and reverse motion along NE Prince Patrick Fault-A and -B occurred. A northeast-trending(?) anticline formed between John Point Fault and Jameson Fault-B. The subbasin that had previously received fine-grained overbank sediments thus started accumulating sandstone and chert-limestone-pebble conglomerate derived from both local and extra-basinal sources. Sedimentary environments ranged from braided river to shoreface as the subbasin was reconnected with the sea to the north. Distal marine areas were the locus of deep-water, shale and siltstone slope-to-basinal sedimentation.

Kungurian red shale and sandstone belong to the Sabine Bay Formation, which is part of an unconformity-bounded sequence at the margin of the basin. The correlative sequence in the distal areas lies within the upper part of the Trappers Cove Formation and lower part of the van Hauen Formation.

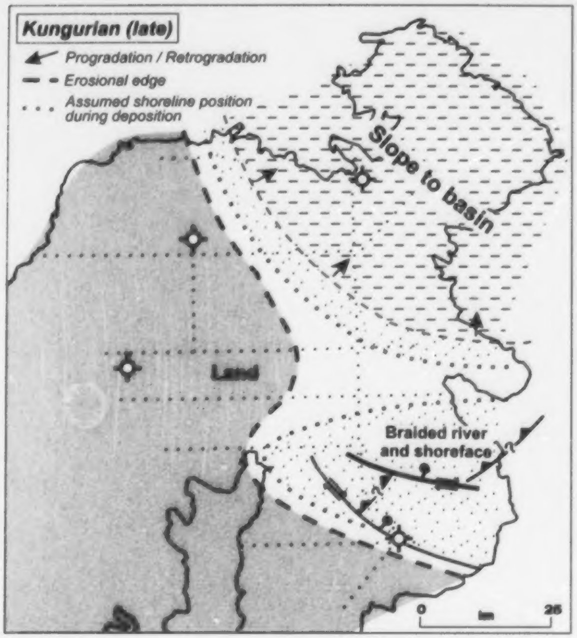
Kungurian (late)
Progradation / Retrogradation
Erosional edge
Assumed shoreline position during deposition
Slope to basin
Land
Braided river and shoreface
0
km
25

Figure 48. *Kungurian (late) paleogeography.*

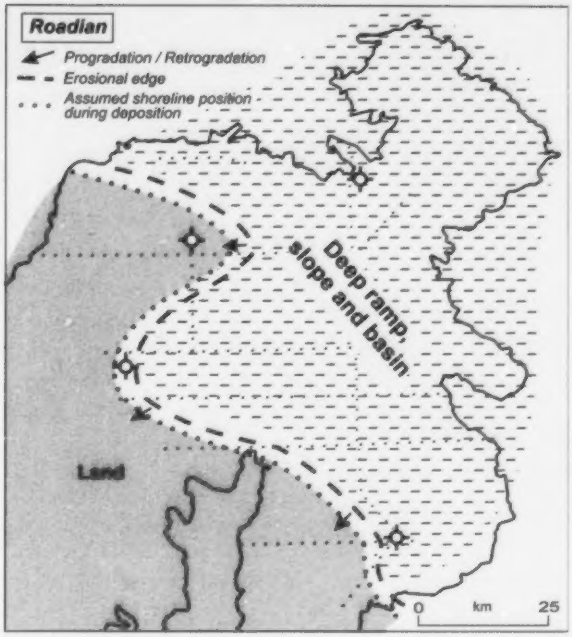
Roadian
Progradation / Retrogradation
Erosional edge
Assumed shoreline position during deposition
Deep ramp, slope and basin
Land
0
km
25

Figure 49. *Roadian paleogeography.*

Roadian

A significant and rapid rise in relative sea level occurred during the Roadian. It led to the drowning of shallow shelf areas, the flooding of the craton and the widespread deposition of a thin, transgressive succession of siltstone and shale over much of northern Prince Patrick Island (Fig. 49). These sediments, which were deposited in deep-water ramp, slope and basinal environments, lie in the lower part of the van Hauen Formation and constitute the transgressive systems tract of the Roadian–Wordian Sequence.

Wordian

Wordian passive subsidence led to the progradation of a significant clastic apron over much of northern Prince Patrick Island (Fig. 50). Gently sloping, shallow- to deep-water chert- and wood-debris-rich sandstone passed laterally into deeper water, slope to basinal siltstone and shale. This clastic wedge was fed by a large, extrabasinal river system draining a major terrigenous source to the south and southwest. The clastic ramp comprises marine sandstone and coarse siltstone of the Trold Fiord Formation. The deep-water, slope-to-basinal shale and fine siltstone belong to the van Hauen Formation. These rocks constitute the regressive systems tract of the Roadian–Wordian Sequence.

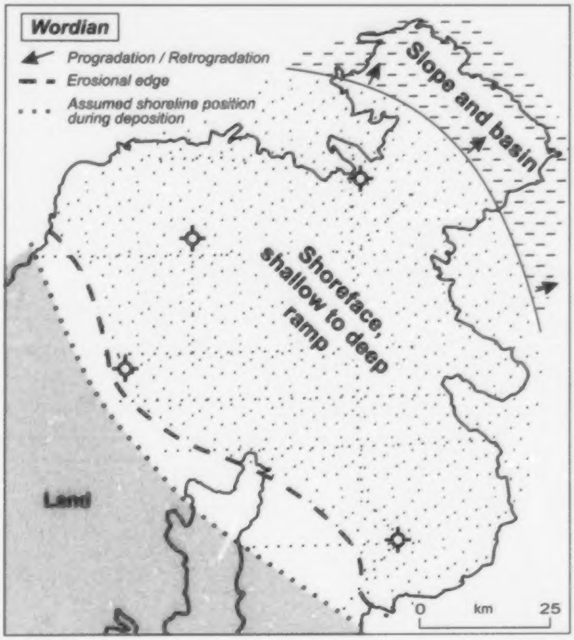
Wordian
Progradation / Retrogradation
Erosional edge
Assumed shoreline position during deposition
Slope and basin
Shoreface, shallow to deep ramp
Land
0
km
25

Figure 50. *Wordian paleogeography.*

Capitanian(?)

A significant rise in relative sea level occurred during the Capitanian(?) interval resulting in the progressive backstepping of the clastic depositional system on northern Prince Patrick Island (Fig. 51). The succession is transgressive and comprises a deepening-upward wedge of sandstone, siltstone and shale that lies within the Trold Fiord Formation. The sandstone was deposited within environments ranging from shoreface to shallow- to deep-water ramp. It passes basinward into finer grained siltstone and shale toward Ballantyne Strait to the north. As for the Roadian–Wordian Sequence, the presence of such a widespread clastic apron is indicative that the area was under the influence of a major river system carrying vast amounts of terrigenous material from the south and southwest. Exceptionally, clastic starvation, perhaps associated with some form of tectonic readjustment, occurred early during the Capitanian(?) and led to the widespread deposition of organic-rich, coaly shale which may or may not represent a hydrocarbon source rock (see 'Economic potential').

REGIONAL AND ECONOMIC IMPLICATIONS

The late Paleozoic geological history of Prince Patrick Island is complex, but in many respects, similar to that of other areas of the Sverdrup Basin. In spite of the uncertainty inherent from the limited stratigraphic and seismic data, the current study provides a wealth of information from a hitherto unknown area. Comparing and contrasting this new information with that of known areas provides a basis for viewing Prince Patrick Island from a basin-wide perspective. It also provides a foundation for reinforcing, modifying or abandoning some of the concepts put forward in previous studies. This final section and accompanying figures (Fig. 52–63) revisits five aspects of the current study: late Paleozoic tectonics, stratigraphic sequences, climatic evolution, clastic influx, and economic potential, and views them through the broader Sverdrup Basin prism.

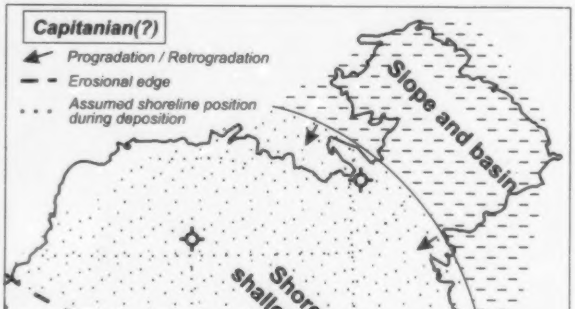
Capitanian(?)
Progradation / Retrogradation
Erosional edge
Assumed shoreline position during deposition
Slope and basin
Shoreface, shallow to deep ramp
Land
0
km
25

Figure 51. Capitanian(?) paleogeography.

Late Paleozoic tectonics

Seismic profiles of the Prince Patrick area provide evidence suggesting that late Paleozoic tectonic pulses, as evidenced by brittle deformation, alternated with episodes of apparent tectonic quiescence and passive subsidence. This conclusion constitutes a significant departure from the established idea that the Sverdrup Basin resulted from a more or less continuous phase of rifting and crustal extension that lasted from the Viséan to mid-Permian, followed by a phase of passive subsidence that extended well into the Mesozoic (Balkwill, 1978; Stephensen et al., 1987; Beauchamp et al., 1989a). That episodic tectonic pulses alternated with episodes of passive subsidence is known from other areas of the Sverdrup Basin as well, where better stratigraphic control has led to the recognition of similar and apparently coeval pulses.

Carboniferous extension

The Sverdrup Basin originated as a rift during the Early Carboniferous, some millions of years following the twilight of the Ellesmerian Orogeny in latest Devonian–earliest Carboniferous time. Three discrete pulses of crustal extension, growth faulting and block rotation led to the formation of the basin. A Viséan pulse led to a handful of small and isolated tectonic depressions (Emma Fiord Formation). A Serpukhovian pulse led to a larger number of tectonic depocentres, mostly aligned along the paleoaxis of the Sverdrup Basin (Borup Fiord Formation). A Bashkirian–Early Moscovian pulse led to a significant enlargement of the basin through the rejuvenation of most basin axial depressions (Otto Fiord Formation) and the addition of many basin margin depressions (Lower clastic member of Canyon Fiord Formation).

There is no evidence that the Viséan pulse affected the Prince Patrick Island area (Fig. 52), although one cannot entirely rule out the possibility that the Viséan Emma Fiord Formation might lie at the bottom of the half-grabens associated with Hemphill Fault-A and Moore Bay Fault-A in the northern part of the island. These two half-grabens are far more likely to have originated from Serpukhovian rifting

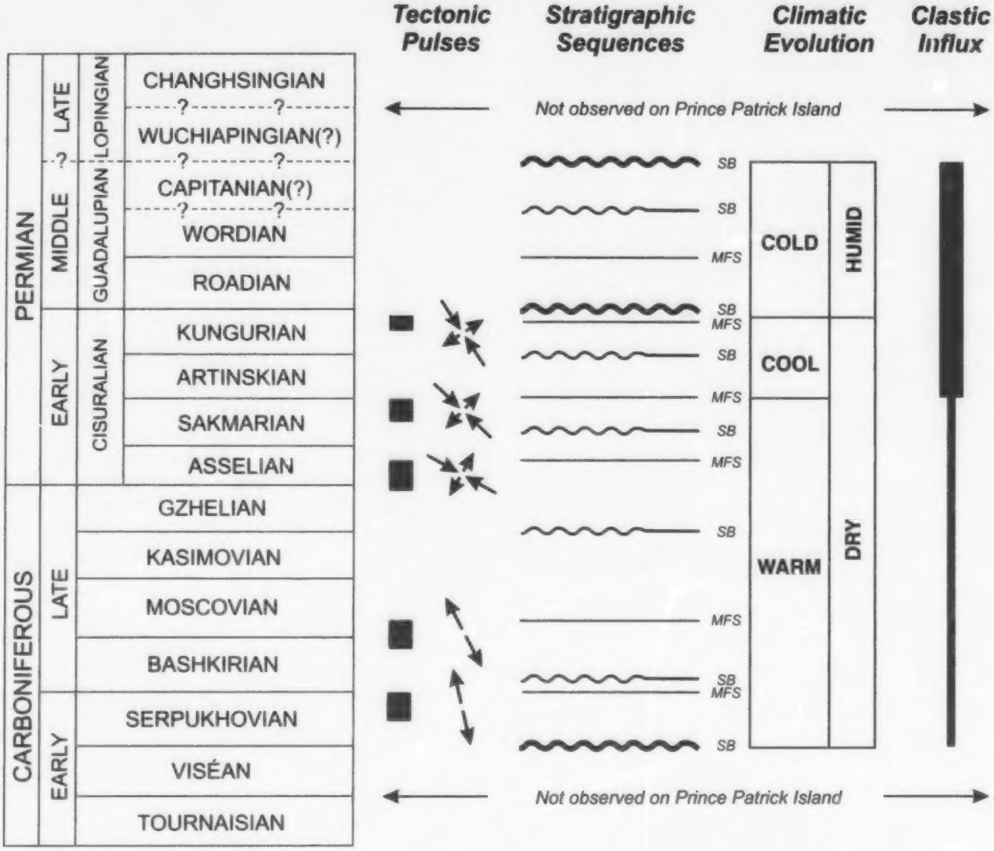

Figure 52. *Stratigraphic chart for the late Paleozoic, Prince Patrick Island, showing temporal relationships between tectonic pulses and their presumed stress orientation, stratigraphic sequences, climatic setting, and clastic influx. See text for explanation.*

(Fig. 52) and hence to contain a succession of Borup Fiord redbeds. The Bashkirian–Early Moscovian pulse (Fig. 52) led to the creation of the two northeasterly trending half-grabens associated with the NE Prince Patrick Fault-A and -B. It may also have led to some movements along the series of named northwest–southeast trending faults.

Various studies have shown that the Carboniferous rifting that led to the formation of the Sverdrup Basin resulted from northerly to northwesterly directed extension (Harrison, 1995; Balkwill, 1978; Meneley et al., 1975; Harrison et al., 1995). Harrison (1995) suggested a north–south principal extension for the Melville Island area. A detailed kinematic study on one specific tectonic depression (Weatherall Depression) indicated a principal transport direction of N10–20°W (Harrison, 1995). Stratigraphic studies have shown that significant normal reactivation of Ellesmerian basement thrusts occurred in areas where such structures are normal or at high angle to the principal direction of extension. Thick half-graben fills of Serpukhovian (Borup Fiord Formation) and/or Bashkirian–Early Moscovian (Lower clastic member, Canyon Fiord Formation) cobble- to boulder-sized, red conglomerate and sandstone are associated with easterly to northeasterly trending basement structures on northern Ellesmere Island (Yelverton Pass area; Mayr, 1992; Thériault et al., 1995a), northwest Ellesmere Island (Hvitland Peninsula; Thériault et al., 1995b), west-central Ellesmere Island (Fosheim and Hamilton peninsulas; Thériault and Beauchamp, 1991), southwest Ellesmere Island (Raanes Peninsula; Thériault, 1991), Grinnell Peninsula (Beauchamp et al., 1998; Beauchamp and Thériault, 1994) and Melville Island (Harrison, 1995; Riediger and Harrison, 1993). In contrast, much thinner and much finer grained successions of red sandstone and rare pebble conglomerate occur in areas where the basement structures are subparallel to the direction of extension, such as on northern Axel Heiberg, where basement thrusts are oriented northwest–southeast.

Prince Patrick Island is one such area where Ellesmerian basement structures are oriented at low angle to the principal direction of Carboniferous extension. The nine northwest–southeast-oriented named normal faults in the area have the same orientation as the basement structures and are obviously kinematically linked to them. Serpukhovian extension apparently occurred along two of these faults (Moore Fault-A and Hemphill Fault-A). However, little extension and block rotation seems to have taken place along any of the northwest–southeast faults during the Bashkirian–Early Moscovian rifting pulse. In contrast, two northeast-trending depocentres bounded by basement highs formed during that time interval. The orientation of these two depressions is consistent with a northerly or northwesterly direction of extension and suggests that they formed in response to normal faulting (NE Prince Patrick Fault-A and -B) at high angle to basement structures.

These observations and interpretations suggest that the principal direction of Carboniferous extension on Prince Patrick Island was the same as throughout the Sverdrup Basin, that is, anywhere from north–south to northwest–southeast (Fig. 52). Normal reactivation of basement thrusts was minimal because these structures were subparallel to the principal direction of extension. It is plausible, however, that these structures acted as transfer faults linking different areas of active extension, and thus were perhaps the locus of left-lateral strike–slip motion. Finally, the difference between the Serpukhovian and Bashkrian–Early Moscovian rifting pattern may be indicative of a minor shift in the direction of extension from an early north–south direction to a later northwest–southeast direction (Fig. 52).

Early Permian compression

Traditional wisdom regarding the tectonic evolution of the Sverdrup Basin dictates that rifting continued during the Early Permian up until the late Artinskian or Kungurian and that the cessation of rifting was accompanied by a short-lived, yet significant, episode of compressive tectonics (see Beauchamp et al., 1989a). Evidence of structural inversion, folding, thrusting, and tilting is widespread beneath the mid-Permian unconformity, both in surface and in subsurface areas. Based on field evidence on Melville Island and southwest Ellesmere Island, Thorsteinsson and Tozer (1970) coined the term Melvillian Disturbance for the mid-Permian tectonic event that affected the Sverdrup Basin. In recent years, the Melvillian Disturbance has been viewed as a short-lived compressive event that marked the transition from rifting to passive subsidence (Beauchamp, 1995; Beauchamp et al., 1989a).

The idea that the Sverdrup Basin remained under a regime of rifting or extensional tectonics prior to the mid-Permian Melvillian Disturbance comes from the presence of synsedimentary normal faults in the Gzhelian to Artinskian succession. Such faults have been observed in outcrops (e.g., Wallace et al., 1994), interpreted from seismic profiles (Harrison, 1995), or inferred from stratigraphic relationships and sedimentary patterns (Beauchamp, 1987; Thériault, 1991; Kells et al., 1995). Such stuctures, however, are commonly at high angle to Moscovian and older basement-parallel rift structures, suggesting a different stress regime.

Evidence of latest Carboniferous–Early Permian compressive tectonics has been mounting in recent years. This evidence includes angular unconformities, broad folding, local thrusting and half-graben inversions, all of which occurred prior to the mid-Permian event. For instance, inversion of a Bashkirian–Early Moscovian half-graben occurred west of Trold Fiord during the latest Carboniferous–earliest Permian time interval. This inversion, which is paleontologically well-constrained, resulted in a major angular unconformity between subhorizontal Gzhelian and Asselian sandstone (Upper clastic member, Canyon Fiord Formation) and a steeply dipping (up to 55 degrees) and folded Moscovian and older succession of carbonate (Middle limestone member) and cobble- to boulder-sized rift-related conglomerate (Lower clastic member).

Based on these findings, it is far more likely that the Sverdrup Basin was under a compressional rather than extensional stress regime throughout the latest Carboniferous–Early Permian interval. According to Harrison (1995), the structural features associated with the Melvillian Disturbance on Melville Island resulted from southeast-directed compressive stress. Harrison (1995) determined a principal transport direction (compression or Sigma 1) of N45W, implying a secondary transport direction (extension or Sigma 3) of N45E (see fig. 188 of Harrison, 1995). These directions of primary compression and secondary extension are entirely consistent with the orientation of latest Carboniferous and Early Permian compressional and extensional features elsewhere in the basin, including Prince Patrick Island.

It is believed that not one but three pulses of southeast-directed compressional tectonics affected Prince Patrick Island during the Gzhelian–Kungurian time interval (Fig. 52). The three pulses, of Gzhelian–Asselian, Sakmarian, and Kungurian age, respectively, resulted, to various degrees, in northeast–southwest-oriented folds, inversion along the northeast-trending Prince Patrick Fault-A and -B, and normal motion along all or some of the northwest–southeast-oriented faults. A larger number of northwest–southeast normal faults were affected by the

Gzhelian–Asselian pulse than by the later pulses. Conversely, southeast-directed compression appears to have been more intense during the Kungurian pulse than the earlier pulses. These observations suggest that the orientation of compressive stress might have evolved in a clockwise fashion through time (Fig. 52).

The Melvillian Disturbance takes on a new significance when viewed in light of these interpretations. The Melvillian Disturbance *sensu stricto* can be viewed as the phase of Kungurian compression that led to faulting, folding, and tilting. The Melvillian Disturbance *sensu lato* can be viewed as encompassing all three phases of southeast-directed compression that affected the Sverdrup Basin during the Gzhelian–Kungurian interval. In areas where Guadalupian strata (e.g., Assistance or Trold Fiord Formation) rest with an angular unconformity on Upper Carboniferous strata (e.g., Canyon Fiord redbeds), one cannot readily decipher whether the unconformity resulted from a single compressive event (Melvillian Disturbance *sensu stricto*) or a series of events (Melvillian Disturbance *sensu lato*). This is precisely the case around Kitson River, northwest Melville Island, the area where Thorsteinsson and Tozer (1970) first defined the Melvillian Disturbance.

Middle to Late Permian compression(?) or extension(?)

It is generally accepted that the Melvillian Disturbance *sensu stricto* constituted the last phase of late Paleozoic brittle deformation (faulting and folding) in the Sverdrup Basin. A regime of passive regional subsidence, that is, one that does not involve differential subsidence along faults, is widely believed to have prevailed during the Middle and Late Permian and carried on well into the Mesozoic. This view has prevailed for more than two decades (Meneley et al., 1975; Balkwill, 1978) in spite of the observation, for instance, of synsedimentary normal faults in the Guadalupian succession of Melville Island (Harrison, 1995), or of significant Late Permian–Early Triassic uplifts along the Tanquary High, northwest Ellesmere Island (Mayr, 1992). Admittedly, most seismic profiles show very little evidence of Middle to Late Permian faulting and/or folding in the Sverdrup Basin (one notable exception is a regional seismic profile on Sabine Peninsula, northeast Melville Island; Section E of Harrison, 1995), and most structures appear to die at or below the mid-Permian unconformity. Clearly Middle or Late Permian tectonic pulses, if any, must have been mild and of local extent compared to their Early Permian and Early to Late Carboniferous counterparts.

Evidence is mounting, however, for Guadalupian and probably Lopingian differential crustal movements in some specific areas of the Sverdrup Basin. The evidence is commonly stratigraphic, and thus of indirect nature, and revolves around two lines of observations. One is the highly irregular pattern of erosion beneath the sub-Triassic unconformity, a pattern that simply cannot be explained in terms of a regional base-level drop, or by a network of incised valleys, or by residual uplifts left in the wake of the Melvillian Disturbance. For instance, over short distances on southwest Ellesmere Island (Bjorne and Raanes peninsulas), northwest Ellesmere Island (Hvitland and Svatfjeld peninsulas) and northern Axel Heiberg Island, the sub-Triassic unconformity cuts deeply, yet locally, into Permian sequences, and some of these truncations are spatially related to mapped faults. In the area south of Bunde Fiord, northwest Axel Heiberg, the Triassic Blind Fiord Formation rests directly upon the Artinskian Great Bear Cape Formation (Mayr, Beauchamp and Harrison, unpublished data and pers. comm. 1999). The other line of evidence is the irregular onlap pattern of Early Triassic strata over the eroded Permian surface. Significant, yet local, thickness variations are observed in the basal Blind Fiord Formation indicating that the earliest Triassic transgression proceeded over a very irregular, locally uplifted, surface.

Beauchamp et al. (1995b) speculated on the presence of broad, low-amplitude folds within the Middle to Late Permian succession based on the erosion pattern of a Permian chert unit beneath the sub-Triassic unconformity on Hvitland Peninsula, northwest Ellesmere Island, hence implying that compressional tectonics affected the area during the Middle to Late Permian interval. Many of the sub-Triassic features on Axel and Ellesmere islands could indeed be explained in terms of one or more compressive pulses of yet unknown magnitude or orientation. Alternately, because of the presence of Late Permian synsedimentary normal faults on Sabine Peninsula, northeast Melville Island, one cannot entirely rule out the possibility that a renewed phase of rifting, albeit not nearly as significant as its Carboniferous counterpart, might have affected the Sverdrup Basin during the Middle and Late Permian. In either case, and providing the proper stress orientation, either Middle to Late Permian compression or extension could have led to the local reactivation of Carboniferous rift structures and/or Permian compressional structures, which in turn might have led to the differential uplift and erosion of the Permian succession.

Only scant and equivocal evidence of Middle Permian tectonics was observed on Prince Patrick Island. As discussed earlier, this evidence revolves around the observation of anomalous thickness variations at the base of the Capitanian(?) Sequence west and north of Jameson Bay C-31, and the observation of a locally developed toplap surface within the sequence, suggesting synsedimentary differential subsidence and possible inversion of Jameson Fault-B and associated uplift (Fig. 24, 26). These features are observed within the transgressive systems tract of the first high-order sequence nested within the Capitanian(?) Sequence (short-term sequence G6 in Fig. 39). Noteworthy is the fact that the maximum flooding surface of this high-order sequence is represented by organic-rich coaly shale, a possible source rock (see 'Economic potential') that formed at a time of starvation, that is, when clastic material was either prevented from entering the study area and remained trapped somewhere to the south and west, or when the clastic influx was significantly reduced from the source area.

Stratigraphic sequences

Several unconformities and sequence boundaries were observed throughout the upper Paleozoic succession on Prince Patrick Island. These unconformities can be grouped into three categories based on how they can be correlated over large areas (see Embry, 1995).

Firstly, there are the unconformities and sequence boundaries that cannot be correlated beyond a given well. For instance, the numerous unconformities within the Canyon Fiord and Belcher Channel formations in Jameson Bay C-31 fall into that category. A good example of such an unconformity is displayed in the Canyon Fiord core of that well (Fig. 11). The Moscovian to Sakmarian succession of the Sverdrup Basin comprises over one hundred such unconformities, which form the bounding surfaces of short duration (less than 250 000 years), relatively thin (0–10 m) sequences also known as cyclothems (Beauchamp, 1987).

Secondly, some sequence boundaries can be correlated from well to well with confidence over the study area, but not beyond Prince Patrick Island. The bounding surfaces of the various Guadalupian high-order, short-term sequences (G1 to G8 in Fig. 39) fall into that category. They constitute the bounding surfaces of longer duration (1–2 million years) and relatively thick (10–100 m) sequences. About a dozen of such sequences occur within the Guadalupian van Hauen, Degerböls and Trold Fiord formations throughout the Sverdrup Basin (Desrochers and Beauchamp, 1995; Beauchamp et al., 1989b).

Thirdly, some unconformities can be correlated with confidence, not only across the Prince Patrick Island area, but throughout the Sverdrup Basin as well. These unconformities form the boundary of long duration (5–25 million years) and thick (100–1000 m) sequences. Eight such unconformities have been documented in the Sverdrup Basin, seven of which were observed or inferred on Prince Patrick Island (Fig. 52; see also Fig. 3). Of these eight unconformities, three are clearly more significant than the others.

The sub-Carboniferous, the mid-Permian (Melvillian) and the sub-Triassic unconformities are major widespread surfaces that separate the upper Paleozoic succession into two coherent packages, or major sequences (Fig. 52). As seen earlier, the mid-Permian unconformity forms a natural boundary on seismic profiles (see insets in Fig. 24–30), below which faults are numerous and played a major role during sedimentation, and above which faults are rare and hence played only a minor, or no, role at all. The mid-Permian unconformity is correlative with a similar surface in northern Alaska, in north Greenland and in the Barents Sea (Beauchamp, 1995). Put simply, the Carboniferous–Early Permian Sequence, which lies between the sub-Carboniferous unconformity and the mid-Permian unconformity, was associated with episodic tectonic pulses of significant magnitude and regional extent (Fig. 52). In contrast, the middle Permian Sequence, which lies between the mid-Permian unconformity and the sub-Triassic unconformity, was associated with little or no brittle deformation.

The Serpukhovian, Bashkirian, Gzhelian, Sakmarian, and Kungurian unconformities form the bounding surfaces of physically and genetically similar sequences nested within the Carboniferous–Early Permian Sequence (Fig. 52). These unconformities are of significant lateral extent, albeit not as much as the sub-Carboniferous, mid-Permian, and sub-Triassic unconformities, and are associated with the basinward progradation of variably thick clastic or carbonate regressive systems tracts (RST) that rest above well-defined maximum flooding surfaces (Fig. 52). In addition, the transgressive systems tracts (TST) are, in general, partly coeval with the various phases of extensional or compressional brittle deformation (faulting and folding).

Tectonic origin

A temporal, and presumably genetic, link exists between tectonic pulses and the five sequences nested within the broad Carboniferous–Early Permian Sequence (Fig. 52). In nearly all cases, the phases of extensional or compressional brittle deformation are coeval with the upper part of transgressive systems tracts. Crustal deformation led to accelerated differential subsidence, basin fragmentation, local uplifts, marine restriction, clastic entrapment, etc. The lower parts of the transgressive systems tracts also commonly display some of these characteristics but without the evidence of fault activity. It thus appears that many areas underwent broad flexural deformation prior to the more intense brittle deformation. One example of this may be the development of a broad fluvial basin north of Jameson Bay C-31 prior to Kungurian faulting and folding (Fig. 48). Likewise, the widespread regional sequence-bounding unconformities may also reflect some tectonically related regional uplift that predates the onset of flexural deformation, which itself predates brittle deformation. Harrison (1995) viewed the mid-Permian unconformity as resulting from a broad regional uplift. This may be the case for all low-order unconformities, although one cannot entirely rule out a eustatic origin for some of them.

Tectonic pulses culminated in locally angular unconformities of limited regional extent. A major drowning event invariably occurred immediately after the end of each phase of brittle deformation. This event led to the apparently rapid reconnection of all subbasins (e.g., end of Otto Fiord and Mount Bayley evaporite sedimention on Ellesmere Island) and to the establishment of a regime of passive subsidence that allowed shelf carbonates and/or clastics to prograde basinward over significant distances. As a result, regressive systems tracts form wedges of sediments that were unaffected by faults, and thicken uniformly from their erosional edges to the shelf edges.

In conclusion, each of the five sequences nested within the broad Carboniferous–Early Permian Sequence appears to represent the stratigraphic record of a complete tectonic cycle, that is, from an initial regional uplift (unconformity), to a phase of broad flexural deformation (early TST), followed by a pulse of brittle deformation (late TST) that culminated in a locally angular unconformity. This was followed by rapid drowning (crustal collapse) and then by a regime of passive subsidence (RST). Beauchamp (1997) has interpreted these sequences as resulting from the episodic buildup and release of tectonic stress.

Climatic evolution

The Sverdrup Basin area evolved from warm, tropical conditions during the Viséan–Sakmarian interval to increasingly colder conditions until the end of the Permian. This climatic change is well documented by the distribution of climatic indicators in nonmarine and marine strata (Beauchamp, 1994). Climatically sensitive features and characteristics include the composition of shallow-water biota; the mineralogy of biotic and abiotic elements; and the presence or absence of aragonitic and/or calcitic ooids, oncoids, bryozoan and/or algal reefs, aragonite and/or calcite marine cements, dropstones, evaporites, redbeds, *Microcodium*, caliches, and coals. The distribution of the last five indicators also provides evidence that relatively humid conditions existed during both the Viséan and the late Kungurian–Roadian intervals, and that relatively dry conditions existed in the intervening Serpukhovian–early Kungurian interval (Beauchamp, 1994).

The impoverishment of shallow-water biotic assemblages with time is particularly striking. Sakmarian and older warm-water carbonates contain a plethora of carbonate-secreting organisms dominated by several groups of green, calcareous algae (codiaceans, dasycladaceans, phylloid) and foraminifers (fusulinids, small chambered forams, encrustings forams) in addition to a wide variety of bryozoans, echinoderms, brachiopods, molluscs, solitary and colonial rugose corals, red algae, and the reef-forming *Palaeoaplysina*. This warm-water assemblage is referred to as a Chloroforam assemblage (Beauchamp, 1994; Beauchamp and Henderson, 1994; Beauchamp and Desrochers, 1997). Artinskian shallow-water carbonates, in contrast, display an impoverished cool-water assemblage dominated by bryozoans, echinoderms and brachiopods, with rare warm-water holdovers such as fusulinaceans and colonial rugose corals. This assemblage is referred to as a Bryonoderm-extended assemblage. Bryozoans, echinoderms, brachiopods and sponge spicules constitute the biota of shallow, cold-water Wordian carbonates (Bryonoderm assemblage), whereas the Upper Permian shallow-water sediments are dominated by siliceous sponge spicules (Hyalosponge assemblage), indicative of very cold conditions (Beauchamp, 1994; Beauchamp and Desrochers, 1997).

The microfloral data, to a large extent, support the interpretations made from the climatic indicators listed above. For example, in samples from the upper Viséan Emma Fiord Formation at Svartevaeg, Axel Heiberg Island, and Kleybolte Peninsula, Ellesmere Island, there is an abundance of *Densosporites* spp. and *Murospora aurita* (Utting et al., 1989a). According to the work by van der Zwan et al. (1985), this suggests humid conditions. Farther to the south on Grinnell peninsula, Devon Island, the samples are dominated by *Lycospora pusilla, Colatisporites decorus* and *Waltzispora planiangulata*. The common to abundant specimens of *Lycospora pusilla* indicate sufficiently humid conditions for the growth of large trees (arborescent Lepidodendra), although if, as suggested by van der Zwan et al. (1985), *Colatisporites decorus* is an arid indicator, then there may have been dry periods. Clayton (1985) asssigned the Canadian Arctic spore assemblages to the *Monilospora* microflora, which occupied an equatorial to very low-latitude position, and thus the warm, tropical climate inferred from other climatic indicators would be reasonable.

In rocks of Bashkirian to at least Artinskian age, taeniate disaccate pollen are common, with polyplicate pollen becoming common in the Gzhelian (Utting, 1985, 1989). These suprageneric groups are tolerant of arid conditions (Foster, 1979).

In the Kungurian Sabine Bay Formation there is an abundant and varied assemblage of pteridophyte spores and gymnosperm and pteridosperm pollen, suggesting a diverse vegetation growing in a humid climate. In the overlying Assistance Formation (Roadian) there are fewer trilete spores and more taeniate disaccate pollen, which may indicate either a trend toward less humid conditions, or differences in transport within the two facies. In the Wordian Trold Fiord Formation some samples contain abundant taeniate disaccate and polyplicate pollen, whereas in others, trilete spores are common, possibly indicating arid conditions with humid periods. The range of continental temperatures at this time is difficult to determine, although if the microflora were derived from plants growing within the Sub-Angara floral province they may well have lived in relatively high latitudes with a cool climate (Utting, 1994; Utting and Piasecki , 1995). In the chert beds of Guadalupian or younger age, the Hyalosponge assemblage contains only a few species of rare palynomorphs; whether this reflects a very cold climate or not is open to speculation.

The upper Paleozoic succession of Prince Patrick Island adds little to this well-documented climatic trend (Fig. 52). Gzhelian to Sakmarian shallow-water carbonates recovered from cores and cuttings in the Canyon Fiord, Belcher Channel and Raanes formations display typical Chloroforam warm-water biota. Shelf-edge-derived reef-debris from the upper Hare Fiord Formation are from typical warm-water reef carbonates. Artinskian and younger strata are dominated by fossil-poor clastic sediments. Fossils recovered from the deeper-water van Hauen Formation comprise bryozoans, brachiopods and echinoderms. Shallow-water sandstone of the Trold Fiord Formation is generally devoid of calcareous fossils, except for occasional brachiopods, echinoderms, bryozoans, and sponge spicules; that is, a cold-water Bryonoderm biota.

Red shale representing overbank fluvial strata, locally associated with caliche nodules and *Microcodium*, was observed in the lower part of the Kungurian Sabine Bay Formation, throughout the Artinskian 'unnamed clastics' formation and in the upper part of the Asselian and older Canyon Fiord Formation. These occurrences are indicative of relatively dry, at least semi-arid, conditions. In contrast, the upper part of the Sabine Bay Formation, as well as the Trold Fiord Formation, contains a few occurences of black, coaly shale indicative of relatively humid conditions. Abundant wood debris embedded within marine sandstone of the Trold Fiord Formation provides some evidence that the climates remained relatively humid throughout the remainder of the Permian (Fig. 52).

Clastic influx

Upper Paleozoic clastic sediments were deposited along the southern and northern margins of the Sverdrup Basin. Thick accumulations of conglomerate and sandstone derived from both local and distal sources became trapped by tectonic depressions during times of tectonic activity. The rapid base-level rise and drowning associated with the end of tectonic pulses, and the onset of regional passive subsidence, invariably led to a significant backstepping of clastic depositional systems. It also led to the shutting down of the local clastic sources that were associated with tectonic uplifts during the transgressive phases. Basin-fringing marine and nonmarine sandstones strictly derived from extra-basinal sources occur as narrow and relatively thin belts near the depositional edge of regressive systems tracts. In general, basin-fringing sandstone passes basinward over short distances into shelf, shelf-edge, and slope clastic-free biogenic carbonate and chert. While carbonate and chert commonly prograded over considerable distances basinward, pericontinental clastics remained trapped at the basin edge because of ongoing flexural subsidence and associated coastal onlap of the regressive systems tract. It is only during the final phases of RST sedimentation, that is, contemporaneous with the regional base-level fall that led to basin-margin erosion and formation of the sequence-bounding unconformity, that sandstone was finally free to prograde for some distances basinward.

Permian clastic apron

Exceptions to the above pattern occur in areas lying close to the entry points of major extra-basinal rivers. These areas received substantially more clastic sediments and at a rate that could easily outpace passive subidence and the ongoing creation of accommodation space. As a result, these areas display basin-fringing clastic belts that do prograde basinward for considerable distances, occupying the space filled elsewhere by biogenic carbonate and chert. Four such areas exist along the southern margins of the Sverdrup Basin: 1) the Henrietta Nesmith Glacier area of northern Ellesmere Island; 2) the Canyon Fiord area, west-central Ellesmere Island; 3) Cameron Island; and 4) Prince Patrick Island.

Several lines of evidence indicate that a major river system fed the Prince Patrick area with large amounts of clastic material (Fig. 53). Except for a handful of thin occurrences in the van Hauen Formation, no carbonate or chert occurs in the Artinskian and younger succession of Prince Patrick Island. Deep-water slope and basinal chert-free shale and siltstone (Trappers Cove and van Hauen formations) pass upward and cratonward into shelf and pericontinental sandstone ('unnamed clastics' and Trold Fiord formations). The whole Artinskian and younger Permian clastic apron is more than 2 km thick in the northern parts of the island. The Trold Fiord Formation itself is much thicker (1 km) on Prince Patrick Island than anywhere else in the basin (about 100 m on average). The Guadalupian clastic apron extends over 7500 square kilometres, from south of Emerald Isle to some undetermined point northwest of Prince Patrick Island (Fig. 53).

Additional observations point to unusually high clastic influx in the area. Fossils (brachiopods and bryozoans mostly) are rare in the Trold Fiord Formation on Prince Patrick Island compared to other areas, where remarkably rich brachiopod and bryozoan coquinas occur in association with sandstones (e.g., fig. 10C of Beauchamp and

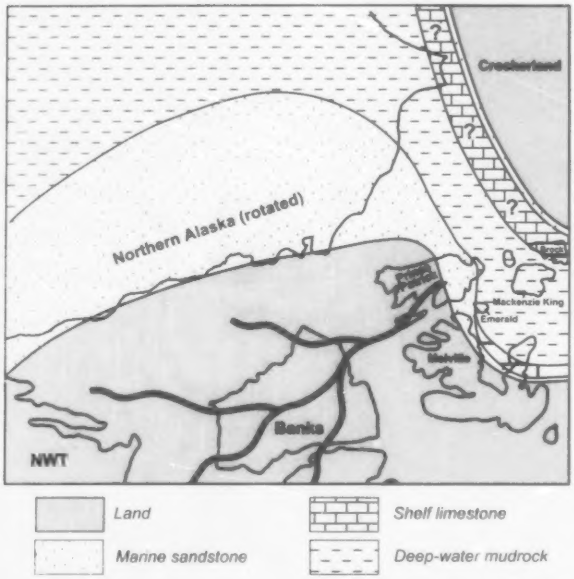

Figure 53. *Guadalupian paleogeographic map of the western Arctic showing a hypothetical basin-fringing river system draining and eroding the area underlain by the Devonian clastic wedge and transporting chert-rich sand into the Sverdrup Basin. The area now occupied by northern Prince Patrick Island was the major entry point of this river system into the Sverdrup Basin. Up to two kilometres of Artinskian and younger Permian clastics lay in the subsurface of Prince Patrick Island. Crockerland is the name given to the late Paleozoic and Mesozoic landmass assumed to have bordered the Sverdrup Basin to the north. Northern Alaska is rotated in a clockwise fashion relative to its current position. Modified from Beauchamp (1995) and Embry (1993).*

Desrochers, 1997). Likewise, sponge spicules and whole sponges, common features in the Trold Fiord, Degerböls, and van Haeun formations in the Sverdrup Basin, are extremely rare in the Trold Fiord and van Hauen formations on Prince Patrick Island. Clearly, high clastic inputs ended up smothering biogenic production on the shelf and adjacent slope.

High sedimentation rates are also indicated by the relatively low glauconite content of Trold Fiord sedimentation on Prince Patrick Island. Glauconite, an unmistakable indicator of slow sedimentation (Odin, 1988), is abundant throughout the Trold Fiord Formation in the Sverdrup Basin, with one notable exception in the Henrietta Nesmith Glacier area, northern Ellesmere Island (Mayr, 1992; Henderson, 1981). Conversely, abundant wood debris (up to 10%) in the Trold Fiord Formation on Prince Patrick Island is indicative of high clastic influx, as preservation of such easily oxidizable material requires relatively rapid burial.

In conclusion, a thick and widespread apron of clastic sediments accumulated on Prince Patrick Island during the Artinskian–Guadalupian time interval (Fig. 53). This apron was fed by an extra-basinal river system that carried large volumes of sand, silt, mud and wood debris into the Sverdrup Basin. *Bona fide* deltaic features (distributary mouth bars, channels, delta plain fluvial overbanks, etc.) are rare and preserved only near the depositional edge of the apron ('unnamed clastics' formation at Andreasen L-32 and Trold Fiord Formation at Intrepid Inlet H-49). The bulk of the apron was a gently sloping, marine sandstone ramp that passed basinward into distal slope to basinal siltstone and shale. To some extent, the entire apron can be viewed as a wave-dominated, deltaic system that received terrigenous sediments from a source area to the south.

Devonian clastic wedge

It is believed that the bulk of the Permian clastic apron on Prince Patrick Island contains material eroded from the Devonian clastic wedge to the south. The Devonian clastic wedge, that is, the erosional product of the Ellesmerian Orogeny, forms a huge foreland wedge that prograded in a southwesterly direction from the middle Devonian to probably the earliest Carboniferous (Embry and Klovan, 1976). It is widely preserved east and south of the Sverdrup Basin, where up to 5 km of clastic material occur. High thermal maturity, however, suggests that a much thicker succession (8–10 km) of Devonian–earliest Carboniferous clastics occurred on Banks Island prior to their subsequent erosion (Embry, 1991).

The high proportion of chert debris in the sand fraction of the 'unnamed clastics', Sabine Bay and Trold Fiord formation sandstones is indicative of a relatively proximal, basin-fringing source. Chert debris is abundant in the upper part of the Devonian clastic wedge, but rare in the lower part. This dichotomy reflects the erosional pattern of the Ellesmerian Orogen – the lower part of the Devonian clastic wedge contains reworked Caledonian material and the upper part is derived from Pearya (Embry, 1991).

Clearly, the major river system that fed clastic sediments to Prince Patrick Island drained an area to the south that was underlain by the Devonian clastic wedge. Chert-rich material in the upper part of the wedge, the last material to arrive as a result of the Ellesmerian Orogen, was the first material to be stripped off by subsequent erosion. This material ended up in the Permian clastic apron on Prince Patrick Island (Fig. 53). Embry (1991) mused about a similar scenario based on the presence of chert pebbles in the Canyon Fiord Formation on Melville Island. Relatively high proportions of chert grains were observed in the Upper clastic member of the Canyon Fiord Formation in Jameson Bay C-31, indicating that shedding of material derived from the Devonian clastic wedge did occur prior to the Permian. Before the Artinksian, however, clastic sedimentation was not widespread enough to smother carbonate sedimentation on Prince Patrick Island, nor on Melville Island for that matter. The profound and irreversible shift in sedimentary regime around the Sakmarian–Artinskian boundary may have been caused by a tectonic event of regional magnitude, such as a broad uplift in the source area. More humid conditions during the Guadalupian must have helped to accelerate the erosion, transportation and deposition of material from the Devonian clastic wedge into the Sverdrup Basin.

Western Arctic paleogeography

The Permian clastic apron peters out east of Prince Patrick Island in the environs of Emerald Isle where Middle to Upper Permian spiculitic cherts are abundant (Fig. 53). The wedge dies out to the north as it passes into deep-water, basin-axial mudrock somewhere beneath Ballantyne Strait. Shallow- to deep-water Middle to Upper Permian chert and carbonate occur farther to the north on Brock Island (Brock C-50 and Brock I-20 wells) and Mackenzie King Island (Wilkins E-60 well), where they represent sediments that accumulated along the northern margin of the Sverdrup Basin (Fig. 53). The western and northwest extension of the clastic apron of Prince Patrick Island is unknown since the Arctic Ocean lies west of the island. One can assume, however, that the northwest–southeast-trending Permian clastic apron extends in the subsurface beneath the Arctic continental shelf to the west up to the point where it meets, at nearly ninety degrees, the edge of the northeast–southwest-trending Arctic continental shelf edge and Canada Basin. The wedge might have been subsequently eroded as a result of uplifts associated with the opening of the Canada Basin.

The origin of the Arctic Ocean and the Canada Basin is open to speculation. In our view, one of the oldest models – the counterclockwise rotation of Alaska – appears to provide the most reasonable hypothesis for accommodating depositional trends in the Sverdrup Basin (Embry, 1993). When northern Alaska is restored to its presumed original position against the Canadian polar continental margin, Hanna Trough, which currently lies in the subsurface of Chukchi Shelf, aligns with the Sverdrup Basin, which trends in a northwest–southeast direction in the western Arctic. It is thus believed that the Sverdrup Basin, Hanna Trough, and Alaska's North Slope formed a continuous depositional system prior to the Cretaceous (Embry, 1993).

Accordingly, the Guadalupian paleogeography of the western Sverdrup Basin aligns nicely with that of northern Alaska when the latter is rotated back to its presumed original position (Fig. 53; see also Beauchamp, 1995). The Permian clastic apron of Prince Patrick Island passes into similar clastic deposits on Alaska's North Slope. These sediments are contained in the Echooka Formation of the Saddlerochit Group. The Echooka Formation comprises up to 200 m of variably glauconitic sandstone that covers a large area of northern Alaska (Beauchamp, 1995; Crowder, 1990). These sediments pass basinward (i.e., southward in current configuration and westward in Permian restoration) into cherty mudrock (Imnaitchiak and Siksikpuk formations), with no intervening carbonate. Like its Prince Patrick counterpart, Middle Permian sandstone of the Echooka Formation was presumably derived from the erosion of the Devonian Clastic Wedge to the east (Fig. 53).

Economic potential

Little is known about the economic potential of the Carboniferous and Permian succession on Prince Patrick Island. Only four exploration wells, drilled between 1971 and 1973, have penetrated the succession, but none of these wells were primarily, or even secondarily, targeting Carboniferous and/or Permian plays. As a result, the oil and gas exploration of this succession is still very much in its infancy and much has to be learned before giving up on hopes of finding a major discovery. The current study, which sheds some light on the upper Paleozoic oil and gas potential of Prince Patrick Island, and indirectly on its mineral potential as well, may help explorationists focus their efforts in the future.

Oil and gas

A large segment of the Permian succession lies in the oil window of thermal maturation and/or in the wet gas and condensates zone (Fig. 54–57; Utting et al., 1989b). As expected, the lowest thermal maturity values, as measured by vitrinite reflectance and by the thermal alteration index (TAI) for palynomorphs, were encountered in the shallowest portion of the succession at Intrepid Inlet H-49 (Fig. 55), where the Trold Fiord Formation straddles the immature gas zone and the marginally mature lower reaches of the oil window. The highest values were encountered in the Hare Fiord and Trappers Cove formations at the bottom of Satellite F-68 (Fig. 57), where thermal maturity data straddle the wet gas and condensates zone and the dry gas zone. On plan view (Fig. 58–62), the oil window forms a broad zone that extends from the erosional edge of the various sequences in the southwest to some distance to the northeast. The oil window is narrowest within the Upper Carboniferous

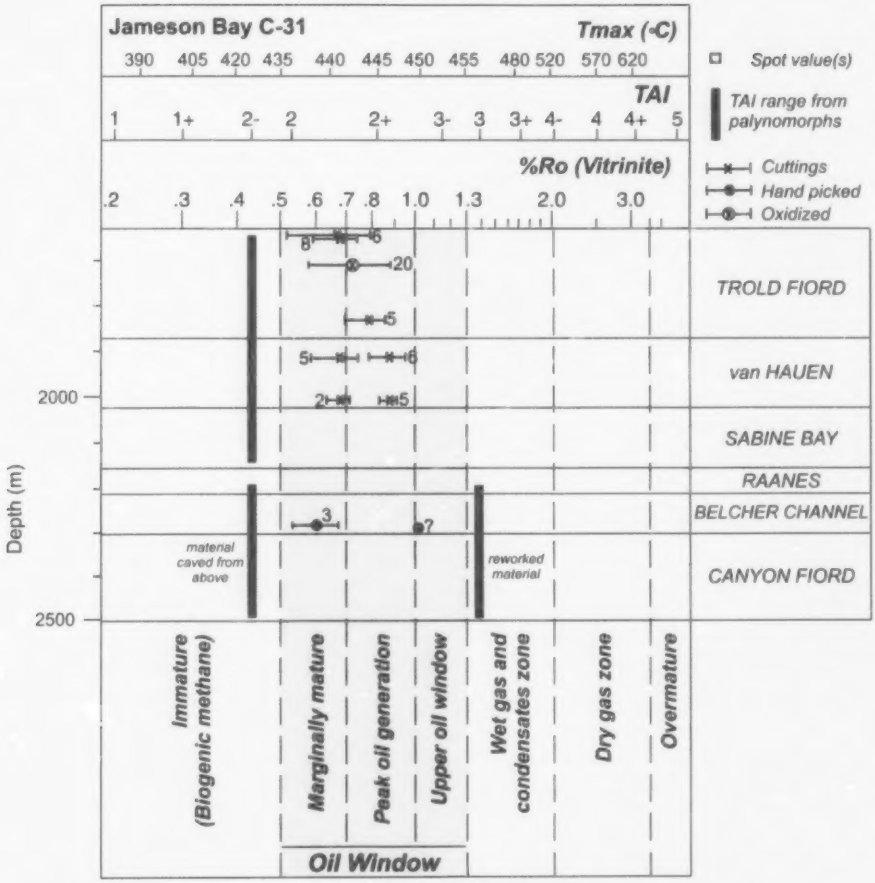

Figure 54. *Thermal maturity data for the Carboniferous and Permian succession of Jameson Bay C-31.*

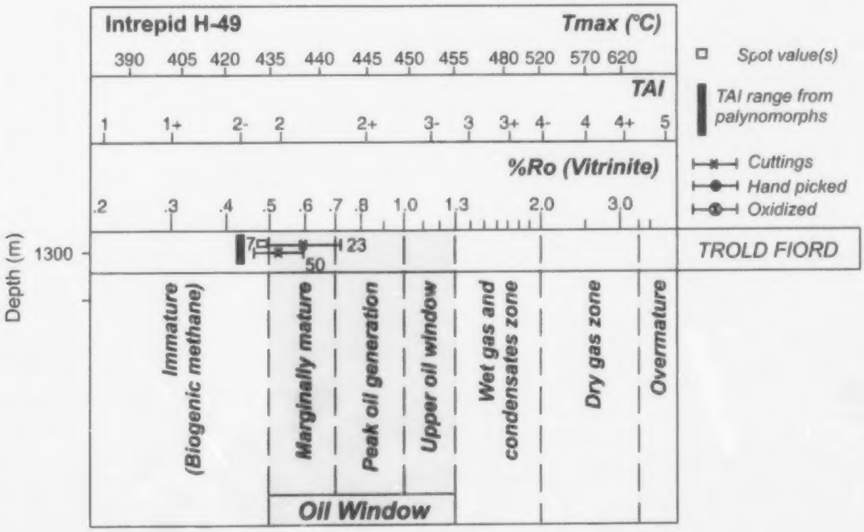

Figure 55. *Thermal maturity data for the Carboniferous and Permian succession of Intrepid Inlet H-49.*

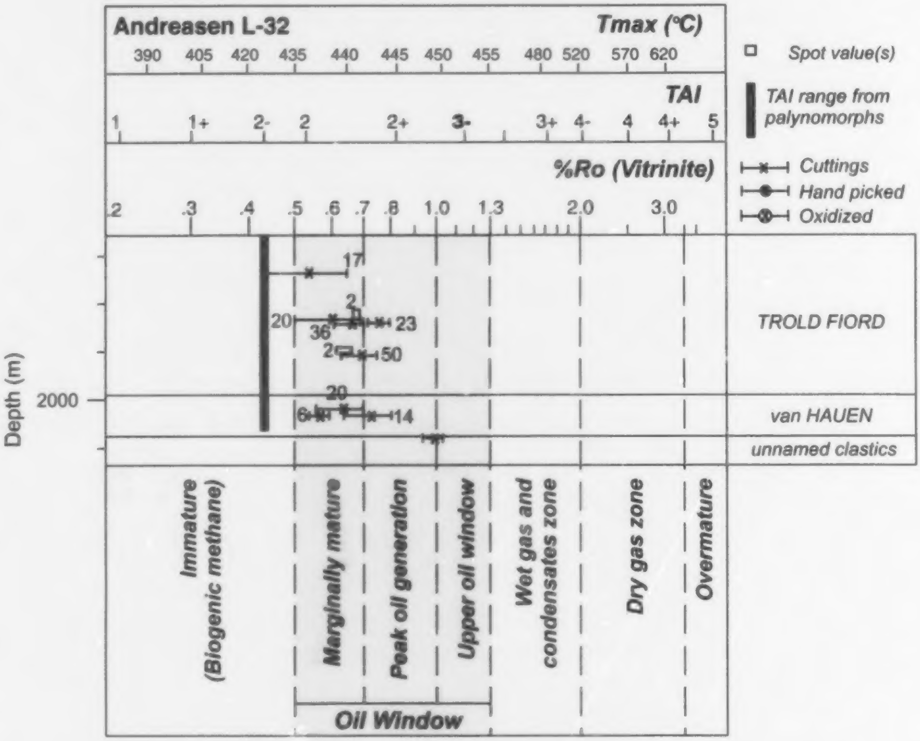

Figure 56. *Thermal maturity data for the Carboniferous and Permian succession of Andreasen L-32.*

succession (Fig. 58) and widest within the Capitanian(?) succession beneath the sub-Triassic unconformity (Fig. 62).

Some of the dark, organic-matter-rich mudrocks of the Hare Fiord, Trappers Cove, and van Hauen formations that occur in the distal portion of the study area may constitute some source rocks. However, it is difficult to geochemically assess the potential of these strata because they lie beneath the oil window, and hence are depleted of much of their volatile organic compounds, as is often the case elsewere in the Sverdrup Basin. One sample of the van Hauen Formation that lies in the lower portion of the oil window at Satellite F-68 has a TOC of 2.4% and yielded some Type III organic matter, which has a poor source rock potential (Fig. 63 and Appendix 2).

In contrast, a series of samples from an organic-rich horizon (TOC 26 to 57%) within the Trold Fiord Formation yielded oil-prone Type I organic matter with excellent source rock potential (Fig. 63 and Appendix 2). This material comes from a thin unit (less than 0.5 m) of black, coaly shale that coincides with the maximum flooding surface of the first high-order sequence within the Capitanian(?) succession (surface 6 in Fig. 39). It can be traced without apparent interruption within the Trold Fiord Formation between Intrepid Inlet H-49, Andreasen L-32 and Satellite F-68, where it is invariably associated with sediments of low sonic velocities (Fig. 7). The origin of this material is yet to be determined and it is unclear to what extent it may comprise condensed terrestrial material washed offshore during a time of shelf starvation. Some of the sampled material comprises *Botryococcus*, an algal spore case commonly associated with Paleozoic source rocks.

Additional source rocks may occur in the proximal settings within the Sabine Bay, Belcher Channel and Canyon Fiord formations. These settings comprise thin, organic-matter-rich horizons within clastic- or carbonate-dominated successions. The source rock potential of these horizons has yet to be determined.

Vast expanses of potentially porous shelf clastics and carbonates lie within the oil window of thermal maturation (Fig. 58–62). The presence of relatively coarse and porous

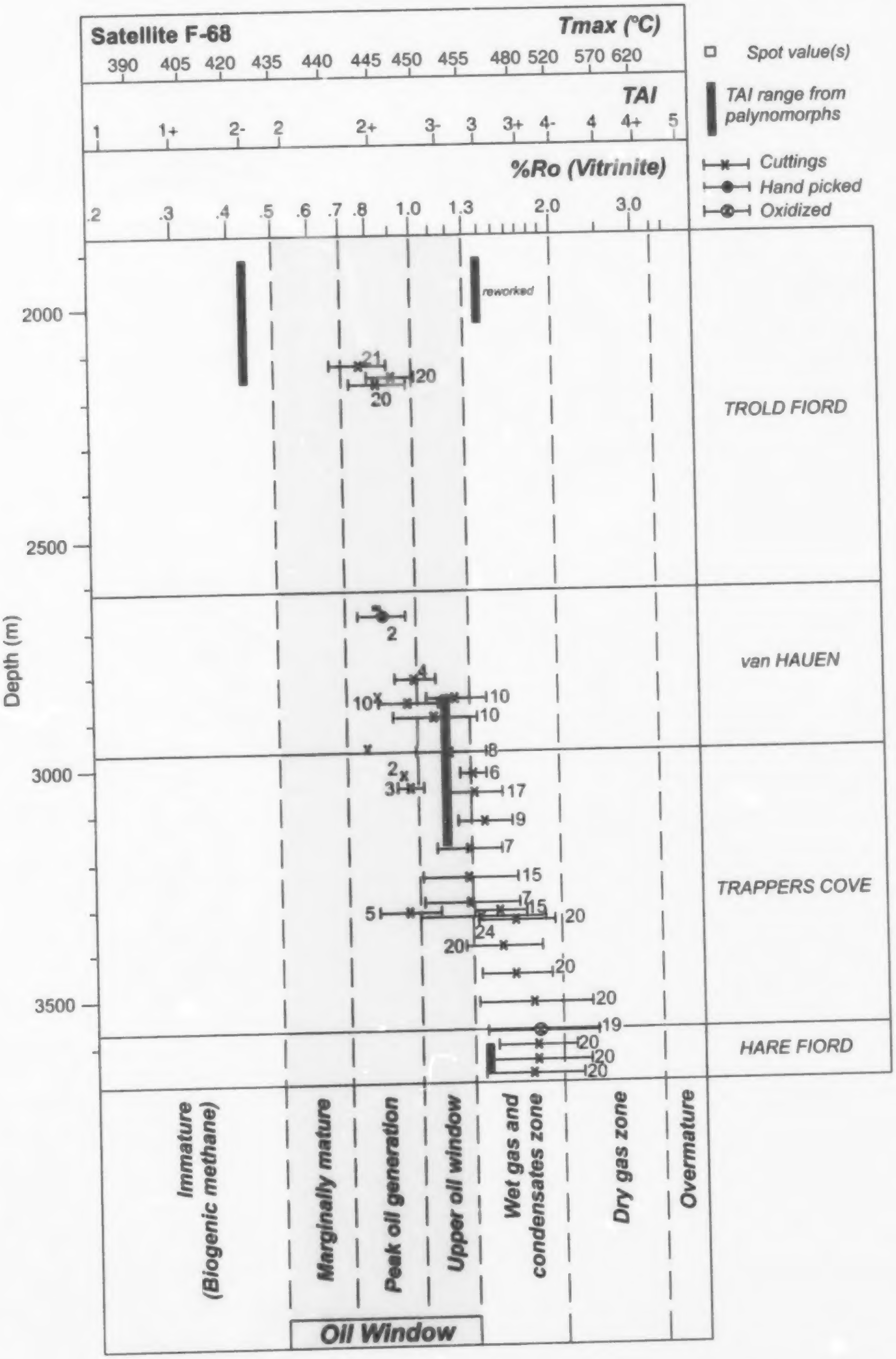

Figure 57. Thermal maturity data for the Carboniferous and Permian succession of Satellite F-68.

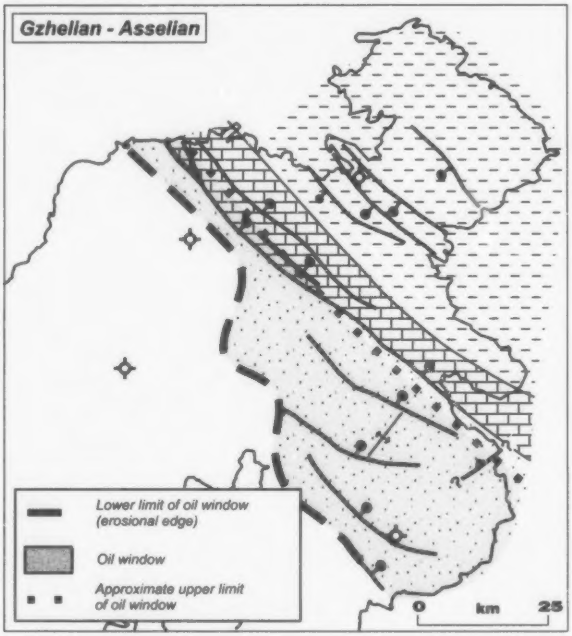
Gzhelian - Asselian
Lower limit of oil window (erosional edge)
Oil window
Approximate upper limit of oil window
0 km 25

Figure 58. Gzhelian–Asselian thermal maturity map superimposed on paleogeography.

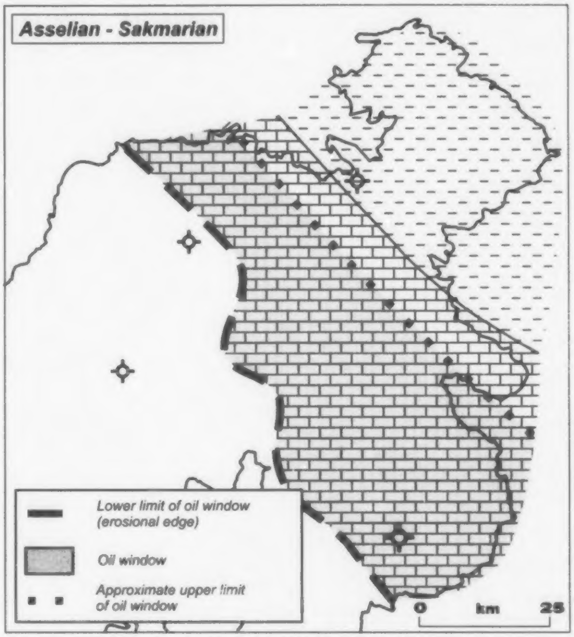
Asselian - Sakmarian
Lower limit of oil window (erosional edge)
Oil window
Approximate upper limit of oil window
0 km 25

Figure 59. Asselian–Sakmarian thermal maturity map superimposed on paleogeography.

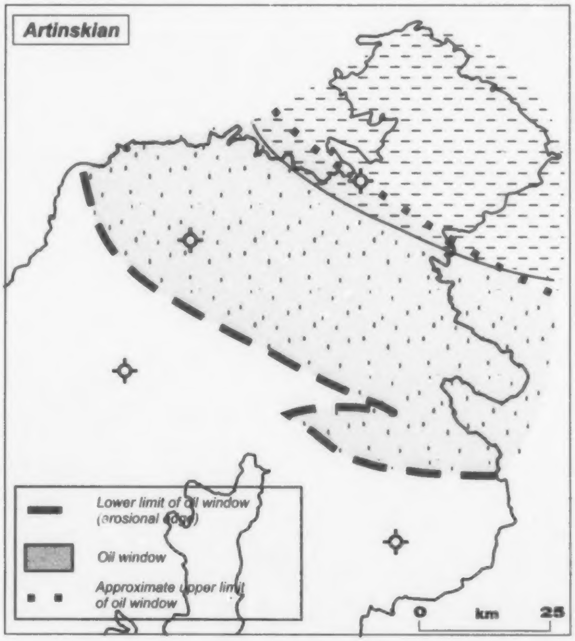
Artinskian
Lower limit of oil window (erosional edge)
Oil window
Approximate upper limit of oil window
0 km 25

Figure 60. Artinskian thermal maturity map superimposed on paleogeography.

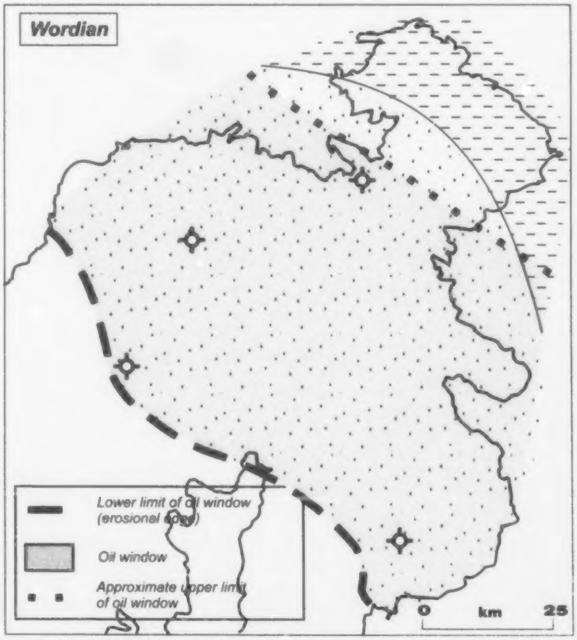
Wordian
Lower limit of oil window (erosional edge)
Oil window
Approximate upper limit of oil window
0 km 25

Figure 61. Wordian thermal maturity map superimposed on paleogeography.

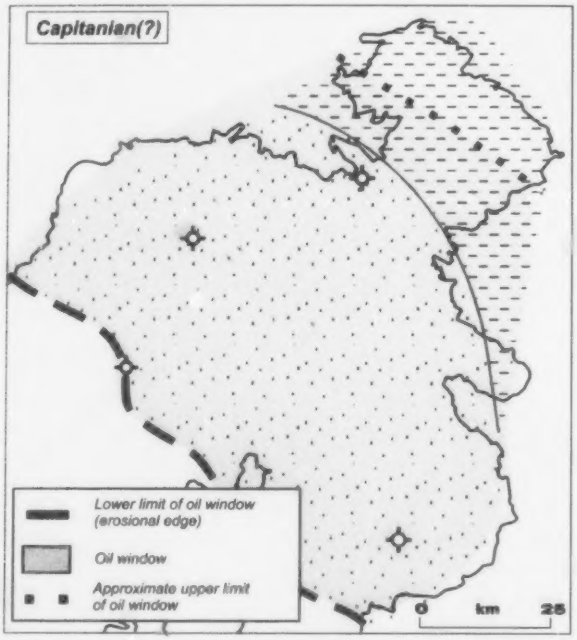
Capitanian(?)
Lower limit of oil window (erosional edge)
Oil window
Approximate upper limit of oil window
0
km
25

Figure 62. Capitanian(?) thermal maturity map superimposed on paleogeography.

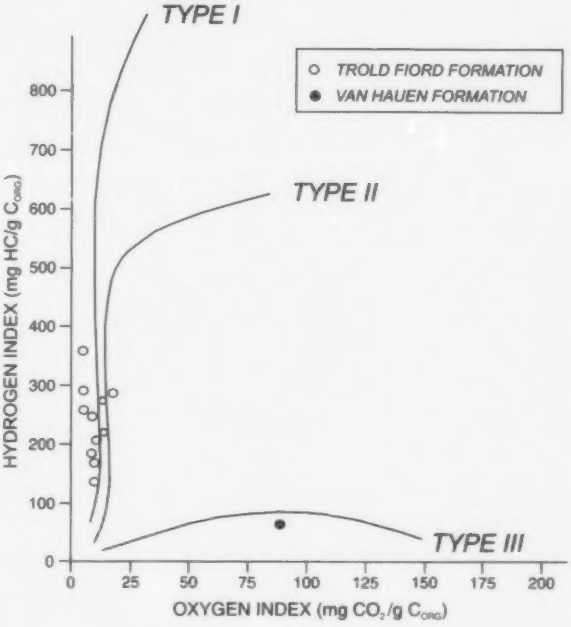

Figure 63. Type of organic matter from material sampled in the Trold Fiord and van Hauen formations in Intrepid Inlet H-49 and Andreasen L-32 based on Rock-Eval analysis (see Appendix 2).

sandstone is suggested at various levels within the Permian succession from the analysis of rock cuttings and various log patterns. Coarse and seemingly porous material lies immediately below the intraformational unconformity within the Trold Fiord Formation, the surface that lies between the Roadian–Wordian Sequence and the Capitanian(?) Sequence. Equally coarse and potentially porous sandstone lies within the upper part of the Sabine Bay Bay Formation, the 'unnamed clastics' formation and at various levels within the Upper clastic member of the Canyon Fiord Formation.

The microscopic analysis of well cuttings suggests less favourable patterns of porosity. Many sandstones of the Trold Fiord, Sabine Bay, 'unnamed clastics' and Canyon Fiord formations are overcompacted, with little or no interparticle porosity left. Those that are normally compacted are commonly cemented by calcite and/or silica cements that obliterate any porosity. Porous sandstones are those that are normally compacted yet only partly cemented as a result of incomplete cementation and/or later dissolution. Carbonate samples of the Belcher Channel and Canyon Fiord formations revealed no observable porosity of any kind.

Many upper Paleozoic hydrocarbon plays remain to be explored on Prince Patrick Island. The most obvious of these is the Moore Bay Anticline (Fig. 5), a broad northwest–southeast-trending Tertiary structure already drilled once at Satellite F-68. Porous sandstone may occur locally along the axis of the anticline within the Trold Fiord Formation, which lies within the oil window. Other porous Wordian and Capitanian(?) Trold Fiord sandstones likely occur throughout the study area, pinching out beneath higher order unconformities and other impermeable surfaces. The best prospects of such stratigraphic traps are probably just beneath the widespread sub-Capitanian(?) intraformational unconformity within the Trold Fiord Formation.

The Sabine Bay Formation offers some interesting possibilities for stratigraphic and/or structural traps sealed by the widespread mid-Permian uncoformity. The two small depocentres separated by the northeast–southwest anticlinal structure just north of Jameson Bay C-31 are certainly worth investigating further (Fig. 8, 24). Some of the most coarse and porous sandstones are likely to occur in these small depocentres, closely associated with organic-rich shaly layers with source rock potential. Likewise, the anticlinal structure between these two depocentres comprises variably porous Asselian, Gzhelian and older sandstones of the Canyon Fiord Formation that also rest within the oil window. The same applies for the anticlinal feature that strikes at high angle to John Point Fault (Fig. 58). Finally, the numerous pinchouts of clastic and carbonate strata associated with block rotation and uplift in the Lower Permian and Upper Carboniferous succession also offer numerous possibilities for stratigraphic and structural traps, even though these deeper plays are more likely to yield gas discoveries.

Minerals

The geological and structural configuration of the Carboniferous and Permian succession displays many settings potentially ideal for a variety of mineral deposits. The best prospects probably lie beneath the widespread mid-Permian unconformity, where the association of synsedimentary normal faults, redbeds, carbonate and mixed clastic-carbonate, deeper water mudrock, and a number of regionally extensive unconformities, including the basal unconformity that separates the Franklinian Basement and the Sverdrup Basin, create a number of settings favourable, at least theoretically, for the concentration of base metals. However, the fact that the upper Paleozoic succession lies deep beneath the subsurface, at depths of 1200 m and more, will prevent any mineral exploration effort in that succession for the foreseeable future, and perhaps forever, barring any fortuitous metal discovery during oil and gas drilling.

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APPENDIX 1

PALEONTOLOGY

Identifications and age determinations by:

JU (John Utting, GSC Calgary)[1]
SP (Sylvie Pinard, GSC Calgary)
RL (Rui Lin, GSC Calgary)

INTREPID INLET H-49

GSC locality C-130631
76°58'27"N, 118°45 '04"W

4160–4240 ft.; 1268–1292 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Alisporites plicatus
Apiculatisporis melvillensis
Florinites luberae
Kraeuselisporites sverdrupensis (abundant)
Leiotriletes ulutus
Neoraistrickia delicata
Protohaploxypinus panaki
Raistrickia enervata
Weylandites striatus

Age (JU): The presence of *A. thorsteinssonii* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

4280–4370 ft.; 1304–1332 m (cuttings)

Pollen and spores (JU)

Ahrensisporites multifloridus
A. thorsteinssonii
Alisporites plicatus
A. splendens
Apiculatisporis melvillensis
Calamospora brunneola
Convolutispora arctica
Florinites luberae
Gordonispora obstaculifera
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia caudicea
N. delicata
Protohaploxypinus panaki

Fungi (JU)

Microsporonites sp.

Acritarchs (JU)

Micrhystridium sp.

Age (JU): The presence of *A. multifloridus* and *A. thorsteinssonii* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

Remarks (JU): The abundance of trilete spores and the rare acanthomorph acritarchs suggest a shallow nearshore-marine environment of deposition. Abundant pteridophyte spores and rare fungal spores suggests a relatively humid climate.

JAMESON BAY C-31

GSC locality C-30208
76°40 '12"N, 116°43 '45"W

5430–5450 ft.; 1655–1661 m (cuttings)

Foraminifers (SP)

Geinitzinid? undet.

Age (SP): Sakmarian or younger.

Remarks (SP): The oblique cut of an undetermined genus – a Geinitzinid form with a bilobed? chamber shape – is observed in this sample. The first bilobed chamber shape genus (*Geinitzina*) appears in upper "Sakmarian" rocks in the Sverdrup Basin, and this taxon ranges up into Wordian rocks.

5430 – 5810 ft.; 1655–1770 m (cuttings)

Pollen and spores (JU)

Alisporites splendens
A. plicatus
Apiculatisporis melvillensis (common)
Calamospora brunneola
Convolutispora arctica

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[1] A composite list of pollen and spore taxa is provided on p. 92

C. perplexa (common)
Cordaitina vulgaris
Florinites luberae
Gordonispora obstaculifera
Grandispora sp. (reworked from Devonian)
Leiotriletes ulutus
Neoraistrickia delicata
Protohaploxypinus perfectus
Vittatina heclae
Weylandites striatus

Acritarchs (JU)

Micrhystridium sp.

Age (JU): The assemblage contains taxa typical of the Roadian to Wordian of the Sverdrup Basin.

Remarks (JU): The abundance of trilete spores and the rare acanthomorph acritarchs suggest a shallow nearshore-marine environment of deposition. Abundant pteridophyte spores suggest a relatively humid climate.

5910–6080 ft.; 1801–1853 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Alisporites plicatus
Apiculatisporis melvillensis (common)
Convolutispora perplexa (common)
Cordaitina vulgaris
Cyclogranisporites franklinii
Florinites luberae
Gondisporites nassichukii
Gordonispora obstaculifera
Kraeuselisporites sverdrupensis
Neoraistrickia caudicea
Neoraistrickia delicata (common)
Leiotriletes ulutus
Protohaploxypinus panaki
Protohaploxypinus perfectus
Vittatina heclae
Weylandites cincinnatus
Weylandites striatus

Fungi (JU)

hyphae

Acritarchs (JU)

Cymatiosphaera sp.
Micrhystridium sp.

Age (JU): The presence of *A. thorsteinssonii* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

Remarks (JU): The abundance of trilete spores and the rare acanthomorph acritarchs suggest a shallow nearshore-marine climate of deposition. Abundant pteridophyte spores suggest a relatively humid climate.

6250–6260 ft.; 1905–1908 m (cuttings)

Foraminifers (SP)

"*Frondicularia*" ? sp.
"*Pseudonodosaria*" sp. ("*Pseudonodosaria*" = *Rectoglandulina*" *sensu lato* of most authors)

Age (SP): Artinskian?–Kungurian or younger.

Remarks (SP): A transverse section of a small foraminifer that probably belongs to "*Frondicularia*" sp. This genus first appears in Artinskian rocks and ranges into Wordian rocks in the Sverdrup Basin. The stratigraphic range of "*Pseudonodosaria*" (=*Rectoglandulina*" of most authors) is not yet well defined in the Canadian Arctic. Its presence in Artinskian rocks is uncertain but this genus has been observed in post-Artinskian rocks (no precise age). This genus is known in other basins in Kungurian to Tatarian sediments.

6220–6330 ft.; 1896–1929 m (cuttings)

Pollen and spores (JU)

Alisporites plicatus
Alisporites splendens
Ancyrospora sp. (reworked from Devonian)
Apiculatisporis melvillensis
Cordaitina vulgaris
Florinites luberae
Gondisporites nassichukii
Gordonispora obstaculifera
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Lophotriletes parryensis
Neoraistrickia caudicea
Neoraistrickia delicata
Protohaploxypinus panaki
Protohaploxypinus perfectus
Punctatisporites glaber
Scutasporites nanuki
Striatoabieites striatus
Vitreisporites pallidus
Vittatina heclae

Vittatina vittifera
Weylandites cincinnatus
Weylandites striatus

Acritarchs (JU)

Cymatiosphaera sp.
Micrhystridium sp.

Age (JU): The presence of *S. nanuki* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

Remarks (JU): The abundance of pollen and spores and the scarcity of acritarchs suggest a shallow nearshore-marine environment of deposition.

6460–6480 ft.; 1969–1975 m (cuttings)

Foraminifers (SP)

"Nodosarid" indet.

Age (SP): Unknown.

6460–6620 ft.; 1969–2018 m (cuttings)

Pollen and spores (JU)

Alisporites plicatus
Alisporites splendens
Apiculatisporis melvillensis
Calamospora brunneola
Diatomozonotriletes hypenetes
Florinites luberae
Gondisporites nassichukii
Gordonispora obstaculifera
Grandispora sp. (reworked)
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia caudicea
Neoraistrickia delicata
Pallidosporites multiradiatus
Potonieisporites sp. A
Protohaploxypinus panaki
Protohaploxypinus perfectus
Punctatisporites glaber
Striatoabieites striatus
Sverdrupollenites agluatus
Sverdrupollenites connudatus
Vittatina vittifera
Weylandites striatus

Acritarchs (JU)

Cymatiosphaera sp.
Micrhystridium sp.

Age (JU): The presence of *S. agluatus* and *S. connudatus* indicates a correlation with the *Alisporites plicatus–Jugasporites compactus* Concurrent Range Zone of Roadian age.

Remarks (JU): The abundance of spores and pollen and the scarcity of acritarchs suggest a shallow nearshore-marine environment of deposition.

6770–6810 ft.; 2063–2076 m (cuttings)

Pollen and spores (JU)

Abiespollenites sp. A
Alisporites plicatus
Alisporites splendens
Apiculatisporis melvillensis
Convolutispora arctica
Cordaitina vulgaris
Cyclogranisporites franklinii
Gordonispora obstaculifera
Grandispora sp. (reworked from Devonian)
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia delicata
Piceapollenites nookapii
Protohaploxypinus perfectus
Verrucosisporites christiei
Vittatina vittifera
Weylandites striatus

Fungi (JU)

Microsporonites sp.

Acritarchs (JU)

Micrhystridium sp.

Age (JU): The overall assemblage indicates a correlation with the *Alisporites plicatus–Jugasporites compactus* Concurrent Range Zone of Roadian age.

Remarks (JU): The abundance of spores and pollen and the scarcity of acritarchs suggest a shallow nearshore-marine climate of deposition. The fungal spores suggest humidity.

6900–7060 ft.; 2103–2152 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Alisporites plicatus
Apiculatisporis melvillensis

Convolutispora perplexa
Corisaccites stradivarii
Florinites luberae
Gondisporites nassichukii
Gordonispora obstaculifera
Grandispora sp. (reworked)
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia delicata
Potonieisporites sp. A
Protohaploxypinus latissimus
Protohaploxypinus panaki
Protohaploxypinus perfectus

Age (JU): The overall assemblage may be assigned to the *Alisporites plicatus–Jugasporites compactus* Concurrent Range Zone of Roadian age. The single specimen of *Ahrensisporites thorsteinssonii* is probably caved (if in situ it would indicate a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age).

7220–7230 ft.; 2201–2204 m (cuttings)

Foraminifers (SP)

Asselodiscus primitivus Mamet and Pinard
Earlandia of the group *E. elegans* (Rauser-Chernoussova and Reitlinger)
Earlandia of the group *E. moderata* (Malakhova)
"*Frondicularia*"? sp.
Geinitzina sp.
ornamented? *Geinitzina* sp.
Globivalvulina sp.
?*Nodosinelloides gracilis* (Potievskaya)
?*Nodosinelloides longa* (Lipina)
Tuberitina sp. (foraminifer?)

Age (SP): Sakmarian or Artinskian.

Remarks (SP): In the Sverdrup Basin, *Nodosinelloides* first appears in early Kasimovian rocks, disappears in later Kasimovian rocks, reappears sporadically in small numbers in the Asselian, and becomes more abundant in Sakmarian rocks. *Nodosinelloides* is identified in Artinskian rocks of the Sverdrup Basin but is not as characteristic there as it is in Sakmarian rocks. *Geinitizina* first appears in Sakmarian rocks (uppermost part) and is still observed in Artinskian and younger? rocks. The association of these two genera suggests a 'late' Sakmarian to Artinskian age. *Nodosinelloides* has not yet been identified in rocks in the upper part of the Artinskian in the Sverdrup Basin. *Asselodiscus primitivus* also has not yet been identified in rocks younger than Artinskian. A poorly preserved transverse section of a small foraminifer could belong to "*Frondicularia*"; if this is the case, the age of this sample would definitely be Artinskian.

7220–7230 ft.; 2201–2204 m (cuttings)

Fusulinaceans (RL)

Schwagerinids

Age (RL): Probably Early Permian.

Remarks (RL): Only one fusulinacean fragment was found in the thin section. It cannot be identified with certainty and a more definite age cannot be assigned.

7230–7280 ft.; 2204–2219 m (cuttings)

Pollen and spores (JU)

Alisporites plicatus
Alisporites splendens
Apiculatisporis melvillensis
Florinites luberae
Gondisporites nassichukii
Kraeuselisporites sverdrupensis
Neoraistrickia delicata
Protohaploxypinus perfectus
Protohaploxypinus sp.
Vittatina connectivalis
Vittatina heclae
V. vittifera
Vittatina sp.
Weylandites cincinnatus
Weylandites striatus

Acritarchs (JU)

Cymatiosphaera sp.
Unellium sp.

Scolecodont (JU)

Algae (JU)

Botryococcus sp.

Age (JU): Two interpretations are possible.
1. The overall assemblage may be assigned to the *Alisporites plicatus–Jugasporites compactus* Concurrent Range Zone of Roadian age, with some reworking of pre-Roadian material.
2. In situ pollen taxa are rare and include *Vittatina* sp. (with a band of exine at the margin) and *Protohaploxypinus* sp.; suggesting a Pre-Roadian age. The taxa of Roadian age are caved.

Remarks (JU): The presence of spores and pollen, rare freshwater algae (*Botryococcus* sp.), rare acritarchs, and a single scolecodont (jaw apparatus of annelid worms) suggests a shallow nearshore-marine climate of deposition.

7410–7430 ft.; 2259–2265 m (cuttings)

Foraminifers (SP)

Biseriella sp.
Earlandia of the group *E. minima* (Birina)
Globivalvulina sp.
Hemigordius? sp. or (or *Neohemigordius*? sp.)
Schwagerinid undet.
Syzrania sp. or *Syzranella* sp.
Tuberitina sp.

Age (SP): Kasimovian–early Gzhelian or late Sakmarian?–early Artinskian?

Remarks (SP): In a cutting of this sample, an axial section of a small foraminifer, probably belonging to *Hemigordius*, is partly dissolved and phosphotized. Because of the poor preservation, I am only able to say that it is slightly probable that this specimen belongs to "*Arenovidalina*". In the Sverdrup Basin, *Hemigordius* has been identified in sediments dated as Kasimovian to "earliest" Gzhelian. In fact, the youngest *Hemigordius* identified in the Sverdrup Basin corresponds approximately to the first *Pseudovidalina*, a genus used locally to define the base of the "Gzhelian" (see Pinard *in* Henderson et al., 1995). According to Chuvashov (pers. comm., 1988), this genus first appears in the uppermost rocks of the Moscovian in the Urals. An immature form of *Neohemigordius* could be mistaken as *Hemigordius*, but *Neohemigordius* is restricted to the uppermost rocks of the "Sakmarian" to lowermost Artinskian(?). Looking at at the shape of the chamber, and how it increases in size with each whorl, I am more inclined to assign the specimen to *Hemigordius*, which has a restricted stratigraphic distribution in the Sverdrup Basin.

7410–7430 ft.; 2259–2265 m (cuttings)

Fusulinaceans (RL)

Eoparafusulina? sp.

Age (RL): Early Permian, probably Sakmarian.

Remarks (RL): Although the present specimen may be a submature individual, it is similar in general shape, septal folding, and chomata to *Eoparafusulina*? sp. aff. *E.*? cheni (Grozdilova and Lebedeva), *Eoparafusulina*? sp. aff. *E.*? dubius (Grozdilova and Lebedeva), and *Eoparafusulina*? sp. aff. *E.*? paraduplex (Grozdilova and Lebedeva), which are the common species in Sakmarian strata at West and East Blind Fiord of Ellesmere Island. Therefore, this interval is probably of early Permian, Sakmarian age.

7550–7560 ft.; 2301–2304 m (cuttings)

Foraminifers (SP)

Earlandia of the group *E. Elegans* (Rauser-Chernoussova and Reitlinger)
Globivalvulina sp.
?*Nodosinelloides longa* (Lipina)
Syzrania bella Reitlinger
Syzranella higginsi Pinard and Mamet

Age (SP): Kasimovian or younger.

Remarks (SP): In the Sverdrup Basin, the first *Nodosinelloides* appears at the base of the Kasimovian with *Hemigordius* but disappears above the base. *Nodosinelloides* reappears sporadically in small numbers in Asselian rocks, and becomes more abundant in Sakmarian rocks.

7550–7560 ft.; 2301–2304 m (cuttings)

Fusulinaceans (RL)

Schwagerinids

Age (RL): Late Carboniferous to Early Permian.

Remarks (RL): Poorly preserved specimens, possibly representing *Rauserites*, *Jigulites*, *Daixina* or *Schwagerina* cannot be identified at the species level because of poor orientation.

7620–7630 ft.; 2323–2326 m (cuttings)

Foraminifers (SP)

Globivalvulina nassichuki Pinard and Mamet
Pseudovidalina media? (Wang)

Age(SP): Gzhelian to Artinskian.

Remarks (SP): In the Sverdrup Basin, *Pseudovidalina* first appears at the base of Gzhelian rocks and ranges into the Artinskian, where it is quite rare. The particular species *Pseudovidalina media* (Wang) is known now to be definitely from the Sakmarian and from the rocks referred to informally by Pinard as Sakmarian–Artinskian. If the sample from 7410–7430 ft. (2259–2265 m) is of Kasimovian age, it is inconsistent to have *Pseudovidalina* in deeper levels. Then the only way to explain the occurrence of *Pseudovidalina* in this sample is if the cutting comes from a higher level.

7870–7960 ft.; 2399–2426 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Alisporites plicatus
Apiculatisporis melvillensis
Calamospora brunneola
Cordaitina vulgaris
Gordonispora obstaculifera
Neoraistrickia delicata
Protohaploxypinus panaki
Protohaploxypinus perfectus
Vittatina connectivalis
Vittatina heclae
Vittatina vittifera
Weylandites cincinnatus
Weylandites striatus

Acritarchs (JU)

Micrhystridium sp.

Algae (JU)

Botryococcus sp.

Age (JU): Two interpretations are possible.
1. The overall assemblage may be assigned to the *Alisporites plicatus–Jugasporites compactus* Concurrent Range Zone of Roadian age, with some caving of material of Wordian age (single specimen of *A. thorsteinssonii).* Also, there may be rare reworking of darker brown specimens of Permian (Roadian to pre-Roadian?) age.
2. The only in situ pollen taxa are rare specimens of Permian *Vittatina vittifera* (darker than remainder of assemblage). Thus the lighter coloured Roadian material and rare Wordian specimens may be caved.

Remarks (JU): The presence of spores and pollen, rare freshwater algae (*Botryococcus* sp.), rare acritarchs, and a single scolecodont (jaw apparatus of annelid worms) suggests a shallow nearshore-marine environment of deposition.

7940–7960 ft.; 2420–2426 m (cuttings)

Foraminifers (SP)

Tuberitina sp.

Age (SP): Undetermined.

8140–8250 ft.; 2481–2515 m (cuttings)

Pollen and spores (JU)

Apiculatisporis melvillensis
Corisaccites stradivarii
Florinites luberae
Gordonispora obstaculifera
Grandispora sp. (reworked)
Leiotriletes ulutus
Neoraistrickia delicata
Protohaploxypinus perfectus
Vittatina heclae
Vittatina vittifera
Vittatina vittifera var. *minor*
Weylandites striatus

Acritarchs (JU)

Unellium sp.

Scolecodont (JU)

Fungi (JU)

hyphae

Age (JU): Two interpretations are possible.
1. The overall assemblage may be assigned to the *Alisporites plicatus–Jugasporites compactus* Concurrent Range Zone of Roadian age. Also, there may be rare reworking of darker brown specimens of Permian (Roadian to Pre-Roadian?) age.
2. In situ pollen taxa are rare specimens of *Vittatina vittifera, Vittatina vittifera* forma *minor, Vittatina heclae* (darker than remainder of assemblage). Thus the lighter coloured Roadian material is caved.

Remarks (JU): The presence of spores and pollen, rare acritarchs, and a single scolecodont (jaw apparatus of annelid worm) suggests a shallow nearshore-marine environment of deposition.

ELFEX ANDREASON L-32

GSC locality C-53291
77°11'38" N; 118°14'14"W

5300–5450 ft.; 1615–1661 m (cuttings)

Preservation of palynomorphs poor.

Pollen and spores (JU)

Grandispora sp. (reworked)
Lunatisporites sp.
Striatoabieites richteri
Striatopodocarpites sp.
Uvaesporites imperialis

Acritarchs (JU)

Micrhystridium sp.
Veryhachium sp.

Age (JU): Based on the presence of *U. imperialis* and *S. richteri* an Early Triassic age is proposed.

Remarks (JU): A nearshore-shallow marine environment of deposition is indicated.

5550–5630 ft.; 1692–1716 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Apiculatisporis melvillensis
Gondisporites nassichukii
Protohaploxypinus panaki
Protohaploxypinus perfectus
Scutasporites nanuki
Striatoabieites borealis
Striatoabieites striatus
Verruciretusispora dubia

Age (JU): The presence of *A. thorsteinssonii* and *S. nanuki* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age. The single specimen of *Verruciretusispora dubia* is almost certainly reworked from the Devonian.

6000–6060 ft.; 1829–1847 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Apiculatisporis melvillensis
Alisporites plicatus
Convolutispora perplexa
Cordaitina sp.
Grandispora sp. (reworked from Devonian)
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia caudicea
Neoraistrickia delicata
Protohaploxypinus latissimus
Protohaploxypinus perfectus
Raistrickia enervata
Weylandites striatus

Age (JU): The presence of *A. thorsteinssonii* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

6190–6260 ft.; 1887–1908 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Alisporites plicatus
Apiculatisporis melvillensis
Calamospora brunneola
Gondisporites nassichukii
Gordonispora obstaculifera
Grandispora sp. (reworked from Devonian)
Jugasporites sp.
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Lunatisporites noviaulensis
Protohaploxypinus sp.
Weylandites cincinnatus
Weylandites striatus

Acritarchs (JU)

Micrhystridium sp.

Abundant amorphous organic matter

Age (JU): The presence of *A. thorsteinssonii* and *Scutasporites nanuki* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age. The single specimen of *Lunatisporites noviaulensis* is almost certainly caved from the Triassic.

6730–6750 ft.; 2051–2057 m (cuttings)

Foraminifers (SP)

"*Arenovidalina*" *sensu lato* (= in part *Hemigordius* of some authors)
"*Cornuspira*"? sp.
"*Frondicularia*" spp.
Genus undetermined (multilayer wall structure)
nodosariform section of "*Frondicularia*" or a Nodosarid

Age (SP): Artinskian or younger?

Remarks (SP): The specimens attributed to "*Arenovidalina*" *sensu lato* show some affinity with the specimens illustrated as *Hemigordius* by Gerke and Sossipatrova (1975) from the Artinskian of the Munugudzak Horizon of Russia. The genus "*Frondicularia*" first appears in Artinskian deposits in the geological record. The undetermined genus with a multilayer wall structure at the sutural level may indicate a younger age for this sample.

6760–6820 ft.; 2060–2079 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Apiculatisporis melvillensis
Gondisporites nassichukii
Grandispora sp. (reworked from Devonian)
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia delicata
Protohaploxypinus perfectus
Striatoabieites striatus
Vittatina vittifera
Weylandites cincinnatus
Weylandites striatus

Acritarchs (JU)

Micrhystridium sp.
Veryhachium sp.

Scolecodont (JU)

Amorphous organic matter common

Age (JU): The presence of a fragment of *A. thorsteinssonii* tentatively suggests a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

BP SATELLITE F–68

GSC locality C-58206
77°17'27"N; 116°55'10"W

6250–6270 ft.; 1905–1911 (cuttings)

Foraminifers (SP)

Geinitzinid sp.

Age (SP): Artinskian or younger (probably Ufimian or younger, see following sample).

Remarks (SP): The observed oblique section of a small foraminifer could belong to the genus "*Frondicularia*". Preliminary results from the Sverdrup Basin indicate that "*Frondicularia*" first appears in Artinskian levels (Raanes? and/or Great Bear Cape formations). In the Pre-Ural region, the first appearance of "*Frondicularia*" also occurs in the Artinskian. In northeastern Russia, it first appears in the Munugudzhak Horizon or upper part of Artinskian deposits (Gerke and Sossipatrova, 1975).

6310–6350 ft.; 1923–1935 m (cuttings)

Pollen and spores (JU)

Ahrensisporites multifloridus
Ahrensisporites thorsteinssonii
Apiculatisporis melvillensis
Calamospora brunneola
Gondisporites nassichukii
Gordonispora obstaculifera
Grandispora sp. (reworked from Devonian)
Leiotriletes ulutus
Protohaploxypinus perfectus
Verrucosisporites sp.
Weylandites striatus

Acritarchs (JU)

Micrhystridium sp.
Veryhachium sp.

Age (JU): The presence of *A. multifloridus* and *A. thorsteinssonii* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

6350–6360 ft.; 1935–1939 m (cuttings)

Foraminifers (SP)

"*Frondicularia*" *ganelinae* Karavaeva, 1984

Age (SP): Probably Ufimian.

Remarks (SP): The longitudinal section of "*Frondicularia*" shows the chambers with a distinctive "accent circumflex" (ô) shape with marked depression at the sutures and a very fine wall. This specimen belongs to *Frondicularia ganelinae* Karavaeva, 1984 described from the Upper Permian Omolonskii Horizon (Ufimian) of Russia. According to Karavaeva (pers. comm., 1990), the stratigraphic range of this species in the Omolon Massif is rectricted to the *Frondicularia galinae* Zone of Ufimian age.

6700–6730 ft.; 2042–2051 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Alisporites plicatus
Apiculatisporis melvillensis
Gordonispora obstaculifera
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia delicata
Vittatina vittifera
Weylandites striatus

Acritarchs (JU)

Micrhystridium sp.

Scolecodont

Age (JU): The presence of *A. thorsteinssonii* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

Remarks(JU): The presence of spores and pollen, rare acritarchs, and a single scolecodont (jaw apparatus of annelid worm) suggests a shallow nearshore-marine environment of deposition.

6440–6450 ft.; 1963–1966 m (cuttings)

Foraminifers (SP)

Frondicularid? undet.

Age (SP): Artinskian or younger.

Remarks (SP): With this oblique section of a small foraminifer, it is very difficult to identify the generic level, but by the probable presence of an ornamentation and a thickening of the wall toward the axis of the shell, it is possible to say that the age of this sample is probably not older than Artinskian.

6900–7050 ft.; 2103–2149 m (cuttings)

Pollen and spores (JU)

Ahrensisporites thorsteinssonii
Alisporites plicatus
Apiculatisporis melvillensis
Gondisporites nassichukii
Hamiapollenites bullaeformis
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia delicata
Protohaploxypinus perfectus
Striatoabieites striatus
Vittatina vittifera
Weylandites cincinnatus
Weylandites striatus

Acritarchs (JU)

Micrhystridium sp.

Age (JU): The presence of *A. thorsteinssonii* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

Remarks (JU): The presence of spores and pollen and the scarcity of acritarchs suggest a shallow nearshore-marine environment of deposition.

7120–7131 ft.; 2170–2174 m (cores)

Pollen and spores (JU)

Ahrensisporites multifloridus
Ahrensisporites thorsteinssonii
Alisporites splendens
Apiculatisporis melvillensis
Convolutispora arctica
C. perplexa
Hamiapollenites erebi
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia caudicea
N. delicata
Protohaploxypinus latissimus
P. perfectus
Striatoabieites striatus
Vittatina vittifera forma *minor*
Weylandites segmentatus
W. striatus

Acritarchs (JU)

Micrhystridium spp.

Age (JU): The presence of *A. multifloridus*, *A. thorsteinssonii* and *H. erebi* indicates a correlation with the *Ahrensisporites thorsteinssonii–Scutasporites nanuki* Concurrent Range Zone of Wordian age.

Remarks (JU): Based on the well preserved abundant pollen and spores, few acanthomorph acritarchs, and angular coaly fragments, a nearshore shallow-marine environment of deposition is proposed. The good palynomorph preservation suggests neutral conditions at the sediment–water interface (neither severely oxic nor anoxic). At the site of plant growth, environmental and climatic conditions were favourable for a diverse flora of pteridophytes and gymnosperms as witnessed by the abundant trilete spores, and taeniate disaccate, non-taeniate and polyplicate pollen. The taxa recorded are typical of the Sub-Angaran floral province.

8740–8761 ft.; 2664–2670 m (cores)

Pollen and spores (JU)

Cyclogranisporites sp.
Kraeuselisporites sp.
Neoraistrickia delicata
Weylandites striatus

Acritarchs (JU)

Micrhystridium sp.

Age (JU): Permian.

Remarks (JU): The presence of spores and pollen and the scarcity of acritarchs indicate a shallow nearshore-marine environment of deposition. The sulphide pseudomorphs suggest anoxic conditions at the sediment–water interface.

9410–9440 ft.; 2868–2877 m (cuttings)

Pollen and spores (JU)

Apiculatisporis melvillensis
Convolutispora perplexa
Gordonispora obstaculifera
Kraeuselisporites sverdrupensis
Leiotriletes ulutus
Neoraistrickia delicata
Vittatina sp.

Acritarchs (JU)

Micrhystridium sp.
Unellium sp.

Age (JU): The relatively few taxa present suggest a possible Roadian age.

Remarks (JU): The presence of spores and pollen and the scarcity of acritarchs suggest a shallow nearshore-marine environment of deposition.

12050–12075 ft.; 3673–3680 m (cuttings)

Foraminifers (SP)

"*Frondicularia*"? sp. or (*Geinitzina*? sp.)
Globivalvulina sp.

Age (SP): Artinskian? or Sakmarian? and younger.

Remarks (SP): A small foraminifer (transverse-oblique section) probably belongs to "*Frondicularia*" rather than to *Geinitzina* because the shell is quite flattened, without a well defined bilobed chamber. In the Sverdrup Basin, "*Frondicularia*" first appears in Artinskian rocks and *Geinitzina* first appears in Sakmarian rocks. Because it is difficult to identify the genus with certainty, it can only be said that the age of this level is at least Sakmarian but can be younger; *Geinitzina*? and "*Frondicularia*" have been identified in rocks as young as Kazanian in the Sverdrup Basin.

Composite List of Pollen And Spore Taxa (JU)

Abiespollenites sp. A Utting, 1994
Ahrensisporites microfloridus Utting, 1994
Ahrensisporites thorsteinssonii Utting, 1994
Alisporites plicatus Jizba, 1962
Alisporites splendens (Leschik) Foster, 1979
Apiculatisporis melvillensis Utting, 1994
Calamospora brunneola Virbitskas, 1983
Convolutispora arctica Utting, 1994
Convulutispora perplexa Utting, 1994
Cordaitina vulgaris (Zauer) Varyukhina, 1971 ex. Utting 1994
Corisaccites stradivarii Utting, 1994
Cyclogranisporites franklinii Utting, 1994
Diatomozonotriletes hypenetes Utting, 1994
Florinites luberae Samoilovich, 1953
Gondisporites nassichukii Utting, 1994
Gordonispora obstaculifera Utting, 1994
Hamiapollenites erebi Utting, 1994
Kraeuselisporites sverdrupensis Utting, 1994
Leiotriletes ulutus Utting, 1994
Lophotriletes parryensis Utting, 1994
Lunatisporites noviaulensis (Leschik) Foster, 1979
Neoraistrickia caudicea Utting, 1994
Neoraistrickia delicata Utting, 1994
Pallidosporites multiradiatus Utting, 1994
Piceapollenites nookapii Utting, 1994
Potonieisporites sp. A Utting, 1994
Protohaploxypinus latissimus (Luber) Samoilovich, 1953
Protohaploxypinus panaki Utting, 1994
Protohaploxypinus perfectus Samoilovich, 1953
Punctatisporites glaber (Naumova) Playford, 1962
Raistrickia enervata Utting, 1994
Scutasporites nanuki Utting, 1994
Striatoabieites borealis Utting, 1994
Striatoabieites richteri (Klaus) Hart, 1964
Striatoabieites striatus (Luber and Waltz) Hart, 1964
Sverdrupollenites agluatus Utting, 1994
Sverdrupollenites connudatus Utting, 1994
Uvaesporites imperialis (Jansonius) emend. Utting, 1994
Verrucosisporites christiei Utting, 1994
Verrucosisporites dubia (Eisenack) Richardson and Rasul, 1978
Vitreisporites pallidus (Reissinger) Nilsson, 1958
Vittatina connectivalis (Zauer) Varyukhina, 1971 ex. Utting 1994
Vittatina heclae Utting, 1994
Vittatina vittifera (Luber) Samoilovich, 1953
Vittatina vittifera var. *minor* Samoilovich, 1953
Weylandites cincinnatus (Luber ex. Varyukhina, 1971) Utting, 1994
Weylandites segmentatus Utting, 1994
Weylandites striatus Utting, 1994

APPENDIX 2

GEOCHEMISTRY

Intrepid Inlet H-49

Formation	Depth (ft.)	QTY	TMAX	S1	S2	S3	PI	S2/S3	PC	TOC	HI	OI
Trold Fiord	4230	100.4	428	0.70	21.43	1.61	0.03	13.31	1.84	9.81	218	16
Trold Fiord	4230	10.8	431	4.72	144.07	9.25	0.03	15.57	12.39	50.56	284	18
Trold Fiord	4230	10.6	432	4.71	146.79	8.77	0.03	16.73	12.62	54.10	271	16
Trold Fiord	4230	5.3	432	4.15	132.83	9.81	0.03	13.54	11.41	54.02	245	18
Trold Fiord	4230	5.8	433	3.96	135.86	8.79	0.03	15.45	11.65	57.17	237	15
Trold Fiord	4231	25.2	433	2.10	64.44	2.81	0.03	22.93	5.54	26.35	244	10
Trold Fiord	4231	10.6	434	1.88	55.66	3.30	0.03	16.86	4.79	27.25	204	12
Trold Fiord	4231	10.5	434	1.80	50.28	3.14	0.03	16.01	4.34	26.94	186	11

Andreasen L-32

Formation	Depth (ft.)	QTY	TMAX	S1	S2	S3	PI	S2/S3	PC	TOC	HI	OI
Trold Fiord	6030	100.2	435	0.31	6.02	0.43	0.05	14.00	0.52	3.65	164	11
Trold Fiord	6030	10.1	441	4.85	135.44	2.17	0.03	62.41	11.69	38.05	355	5
Trold Fiord	6030	10.4	441	4.32	134.23	3.36	0.03	39.94	11.54	38.32	350	8
Trold Fiord	6250	101.2	440	0.14	3.32	0.29	0.04	11.44	0.28	2.48	133	11
Trold Fiord	6250	10.6	439	6.60	162.26	3.96	0.04	40.97	14.07	56.70	286	6
Trold Fiord	6250	10.6	439	6.03	148.30	3.96	0.04	37.44	12.86	56.38	263	7
van Hauen	6800	100.1	437	0.02	0.26	0.40	0.07	0.65	0.02	0.45	57	88
van Hauen	9108	100.0	413	0.07	1.25	0.95	0.05	1.31	0.11	2.46	50	38
van Hauen	9108	100.6	414	0.06	1.26	0.95	0.05	1.32	0.11	2.44	51	38